Exploring Caves and Skylights

ASTROBOTIC

NIAC

Red Whittaker

THE ROBOTICS INSTITUTE

Why Caves?

- Moderate Temperatures
- Radiation Protection
- Micrometeorite Protection
- Life Search
- Safe Haven
- Resources
- Origins and Geology
- Agenda from L2


Moon

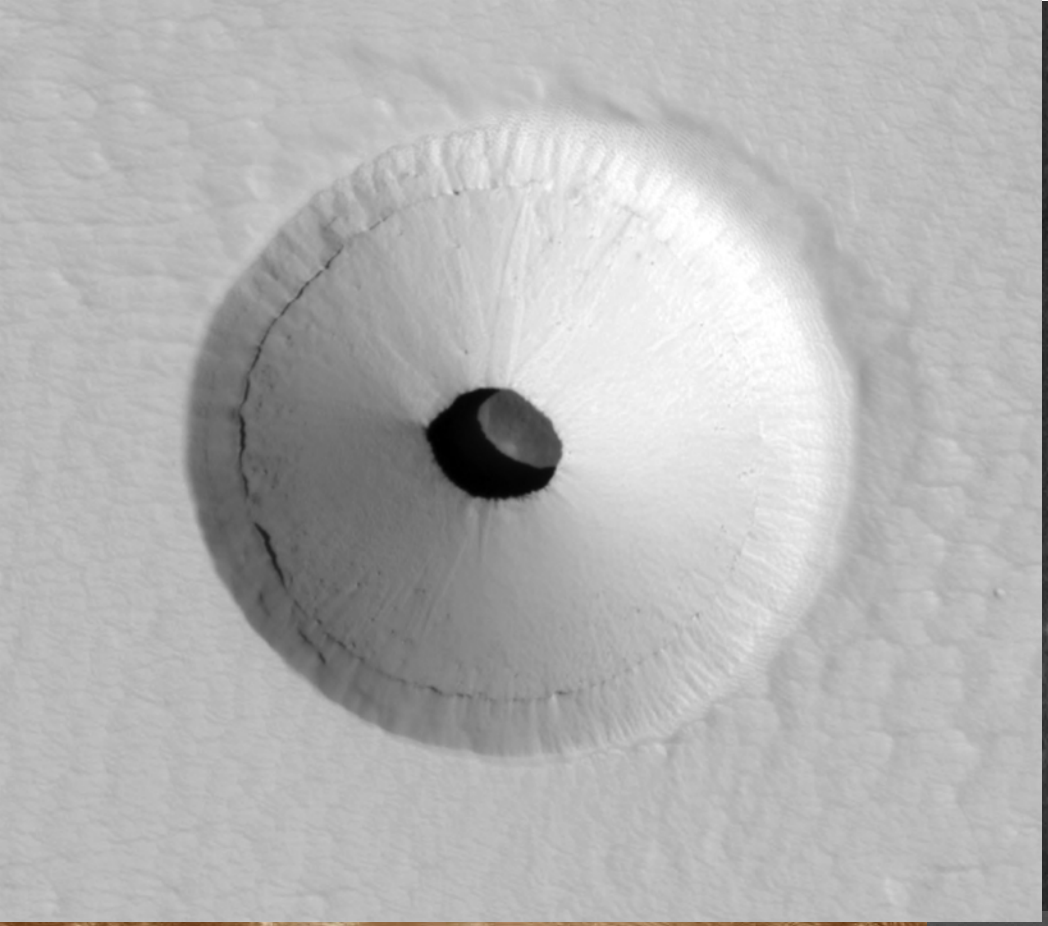
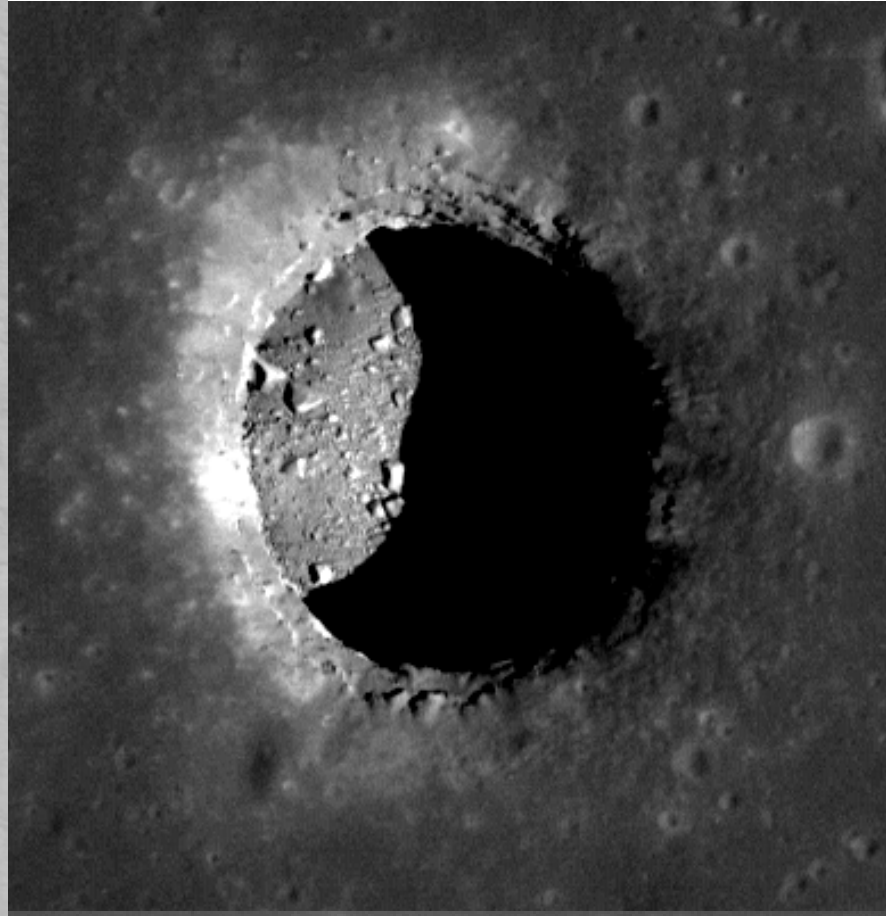
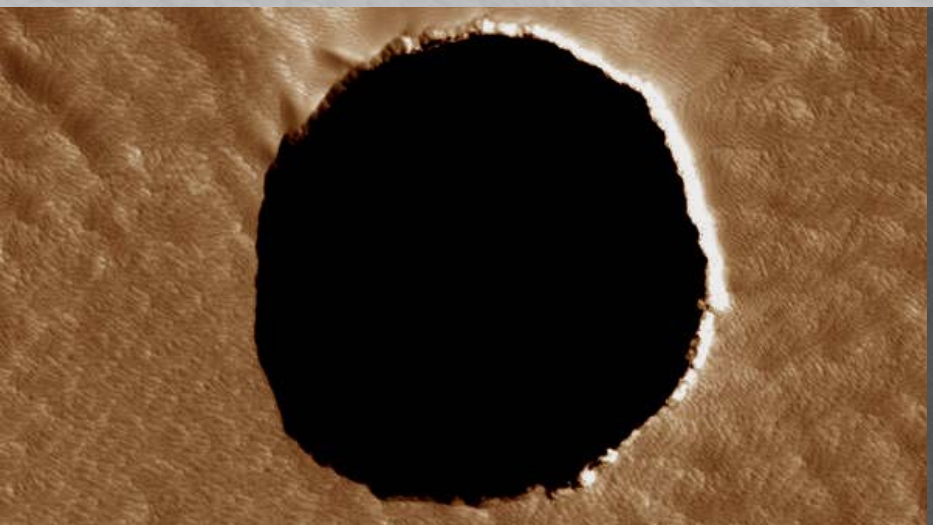
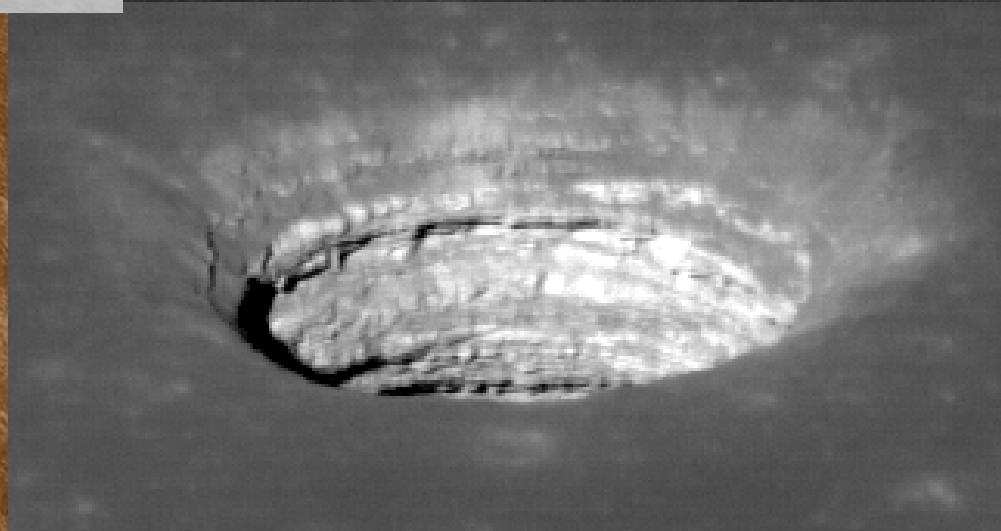
Why Robots for Caves? Caves are:

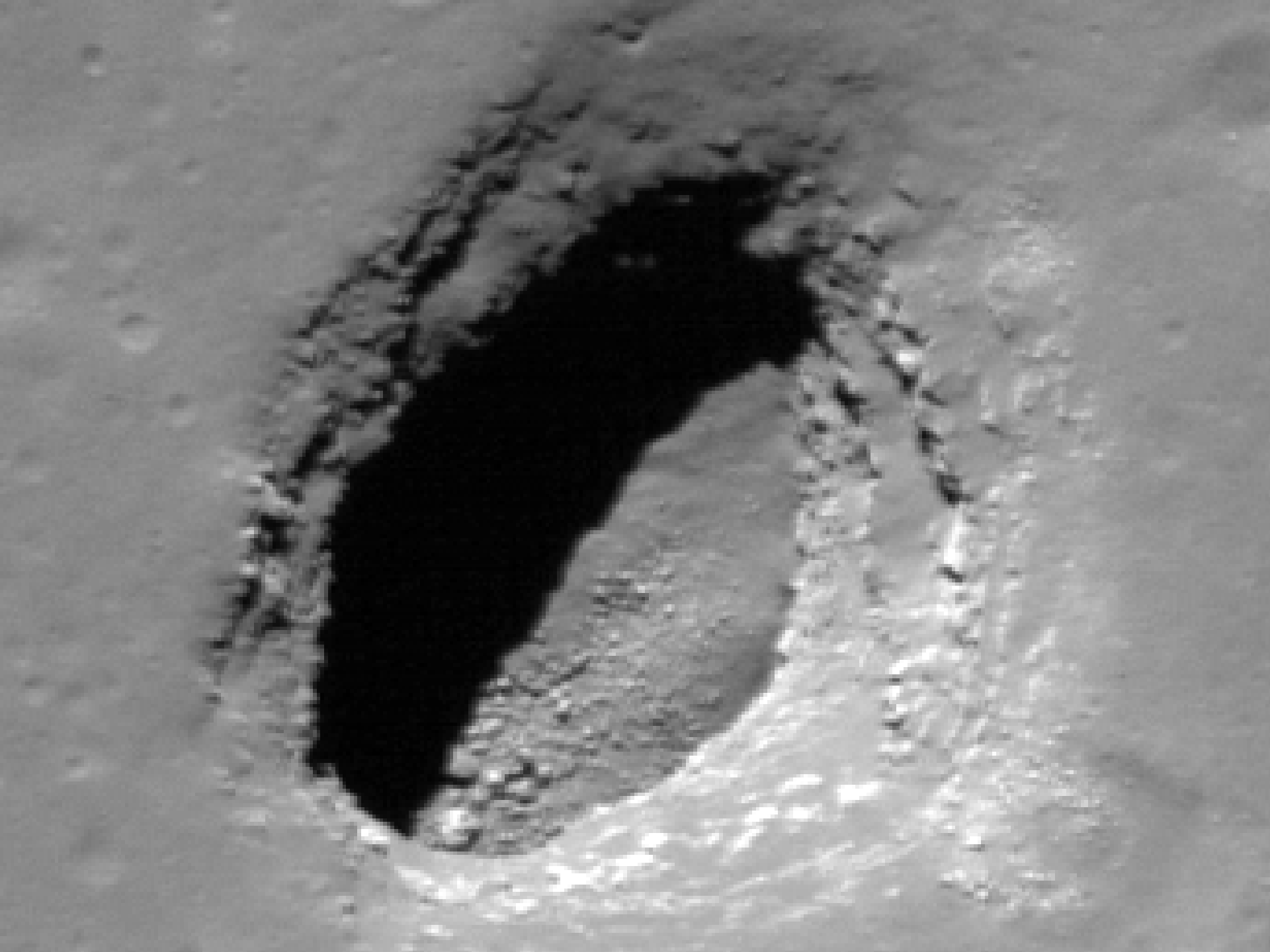
- Unseeable from orbit
- Too risky for humans-first
- Leap of faith for humans before proof of existence, suitability and worthiness
- Economical and Soon

Skylights

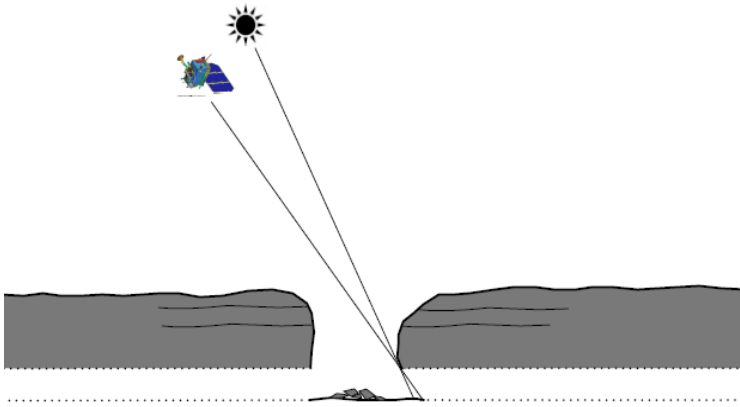
- Holes
- Confirmed on Moon and Mars
- Speculated on Mercury, Venus, and the moons of Jupiter
- Uncertain origin
- One confirmed opening into a cave

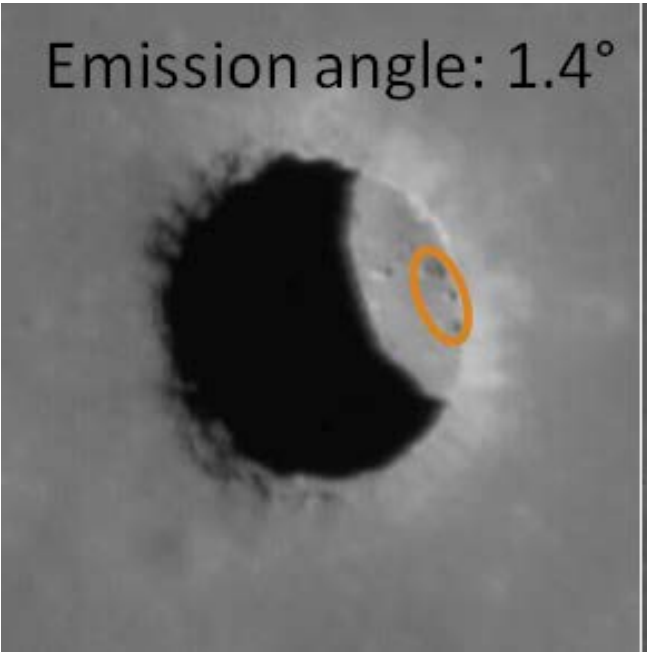
- Really new

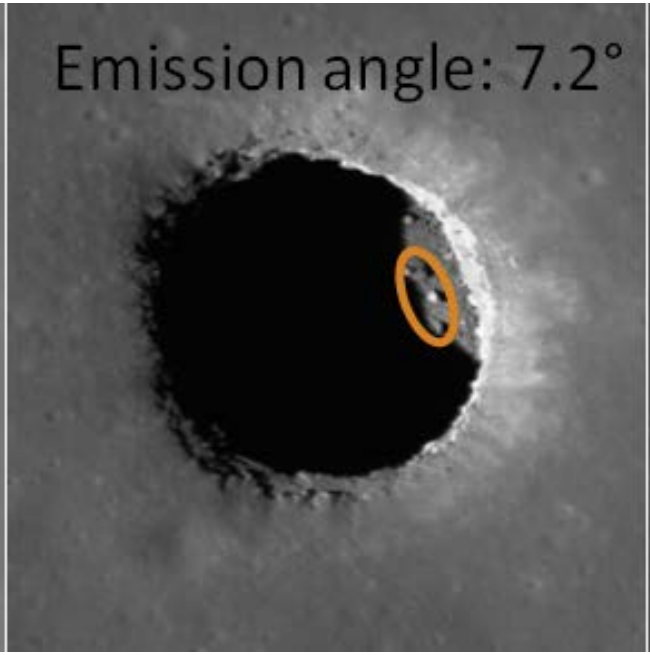





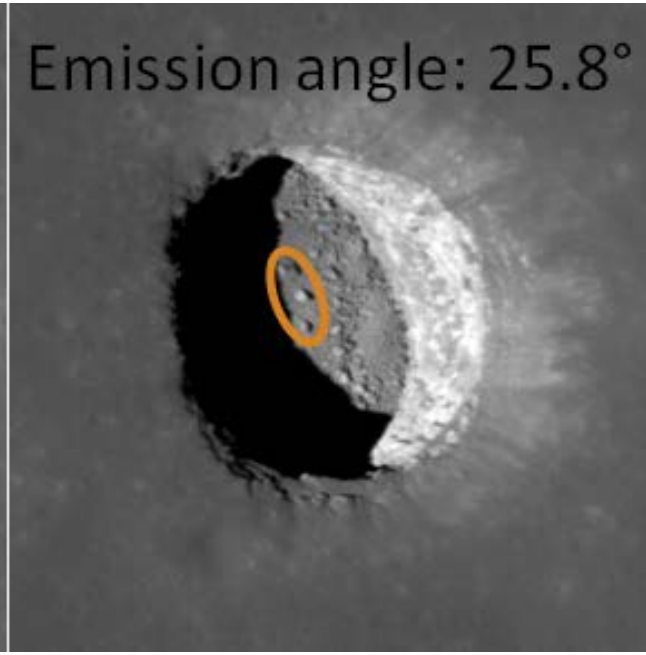


Looking under a rim into a Cave



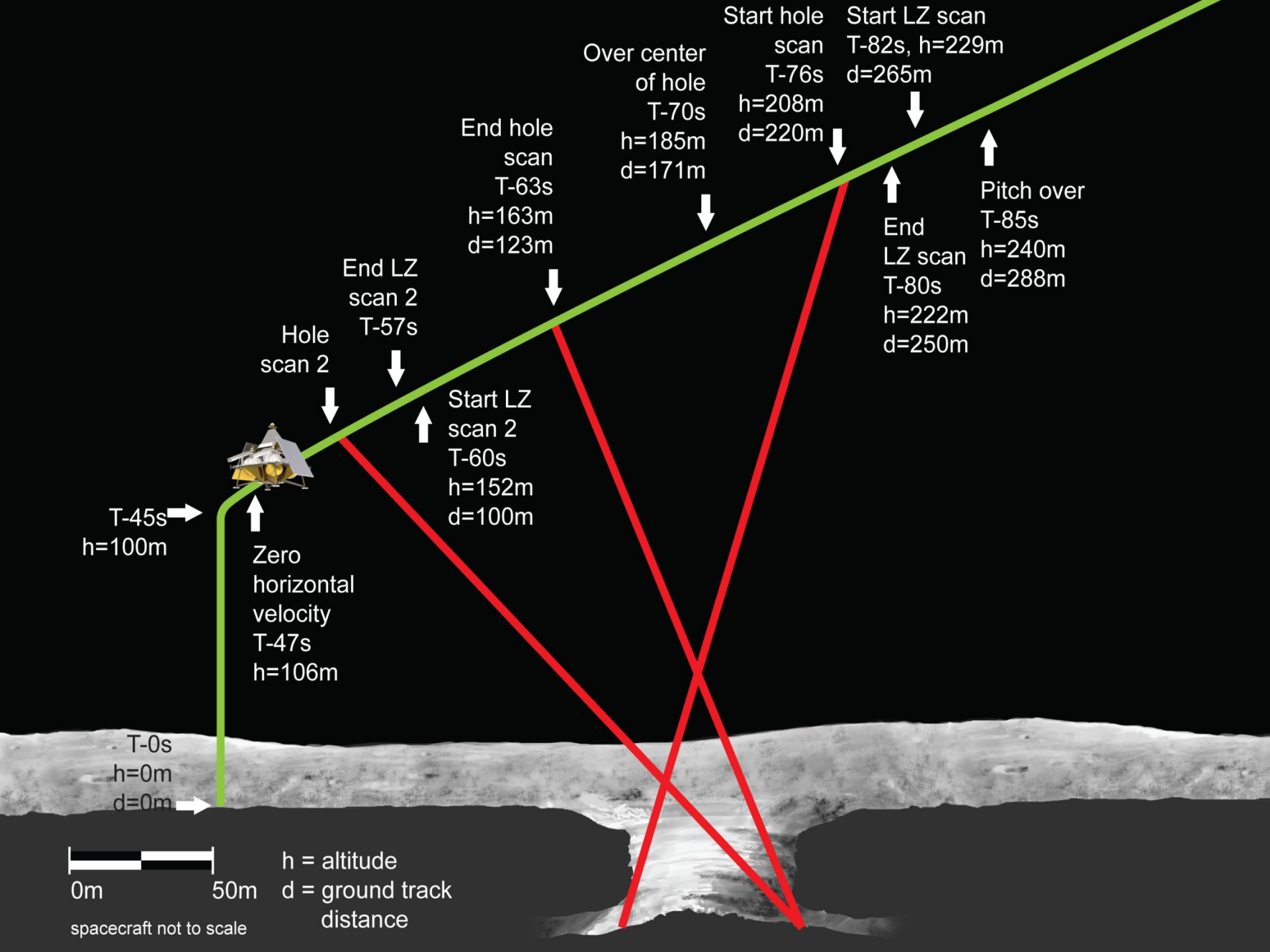




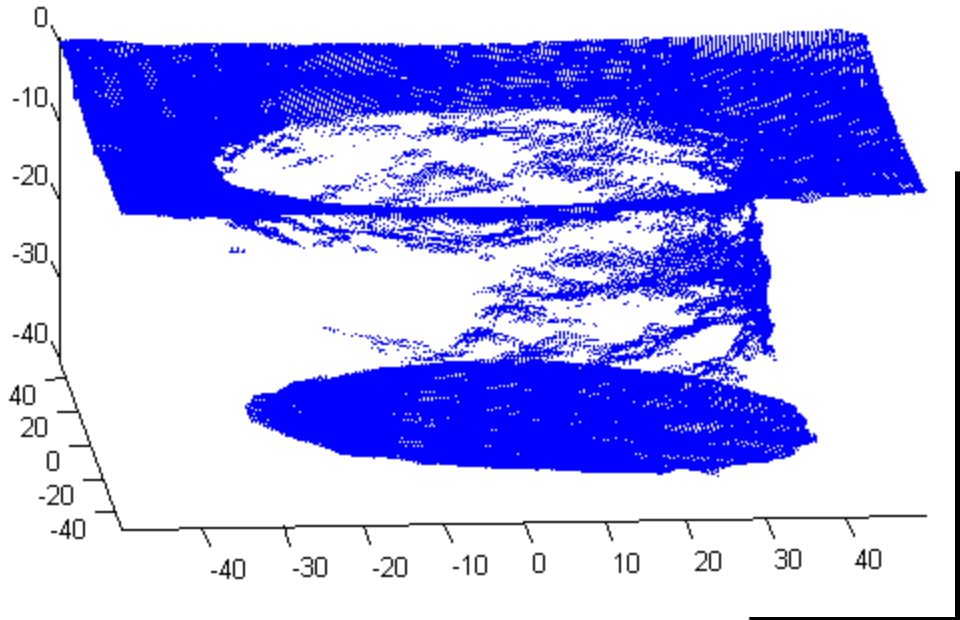


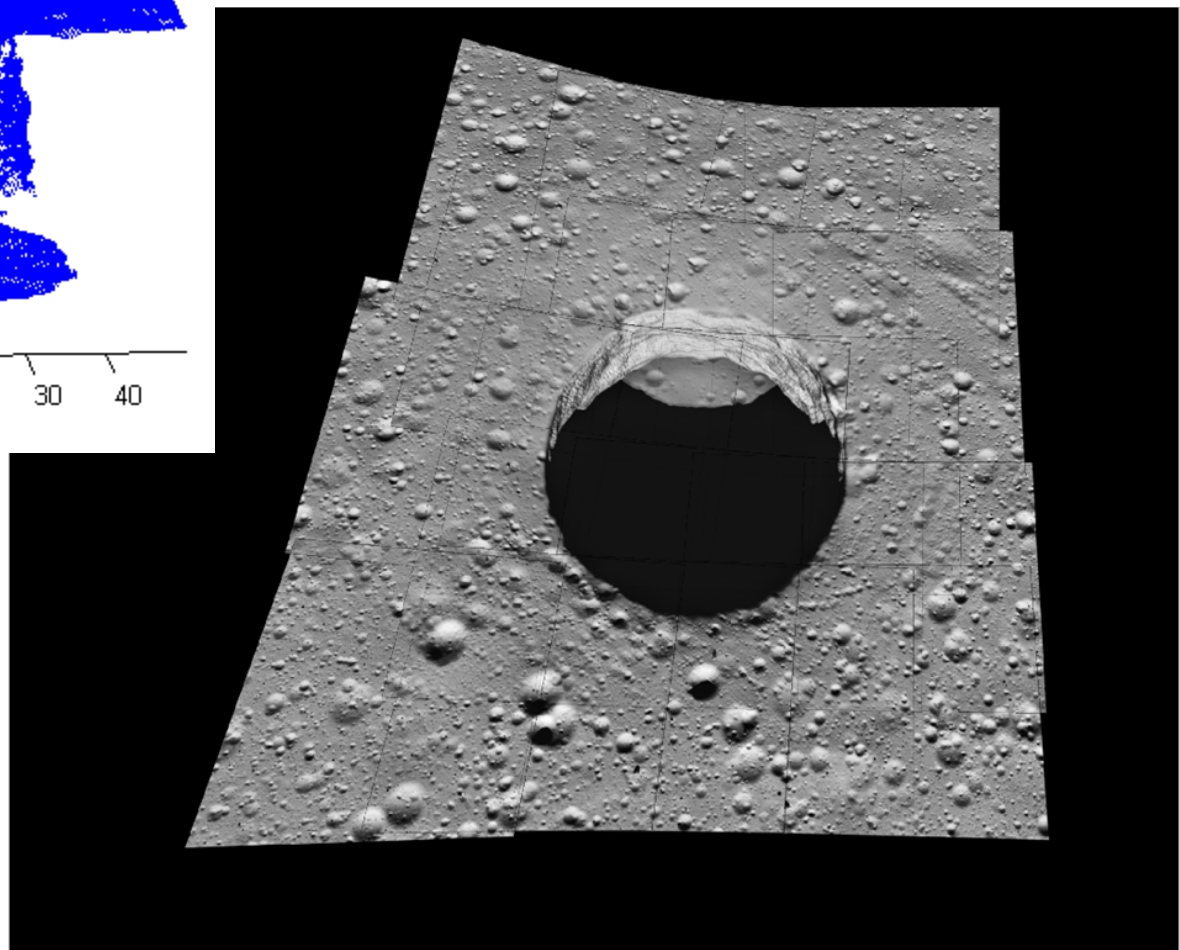
What's Tough ?

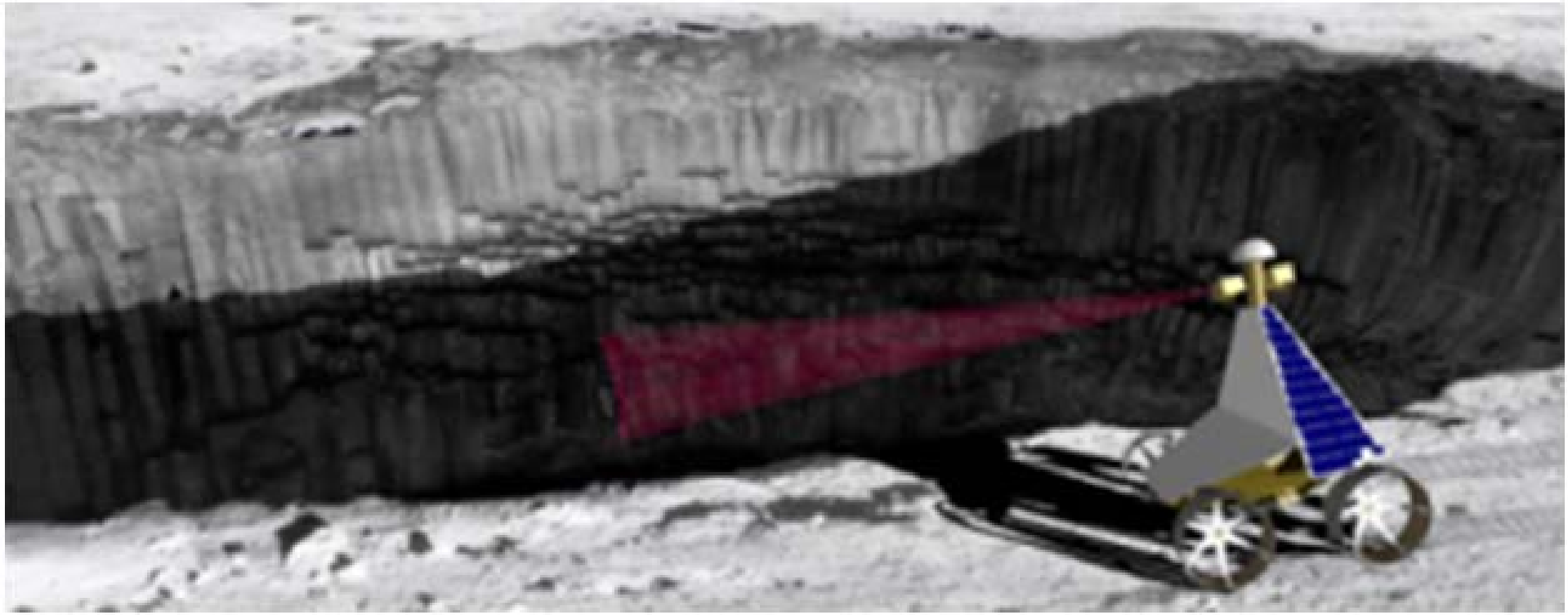
- Flyover modeling
- Apron landing
- Descent and access
- Power
- Mobility
- Comm
- Modeling
- Autonomous Ops


Start hole scan T-76s h=208m d=220m
Start LZ scan T-82s, h=229m d=265m
Over center of hole T-70s h=185m d=171m
End hole scan T-63s h=163m d=123m
End LZ scan 2 T-57s
Hole scan 2
Start LZ scan 2 T-60s h=152m d=100m
End LZ scan T-80s h=222m d=250m
Pitch over T-85s h=240m d=288m
T-45s h=100m
Zero horizontal velocity T-47s h=106m
T-0s h=0m d=0m
0m
50m
h = altitude
d = ground track distance
spacecraft not to scale

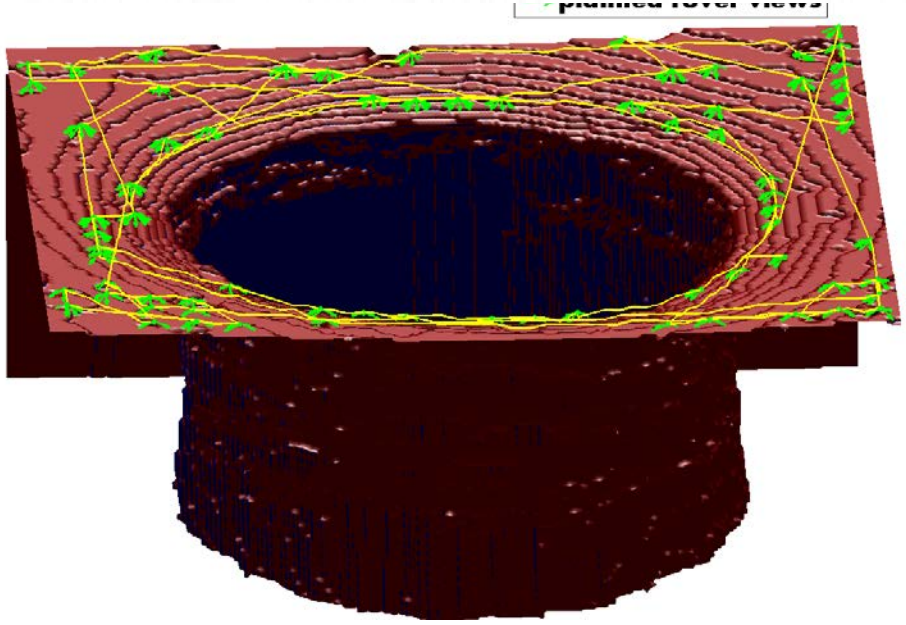
Flyover Modeling



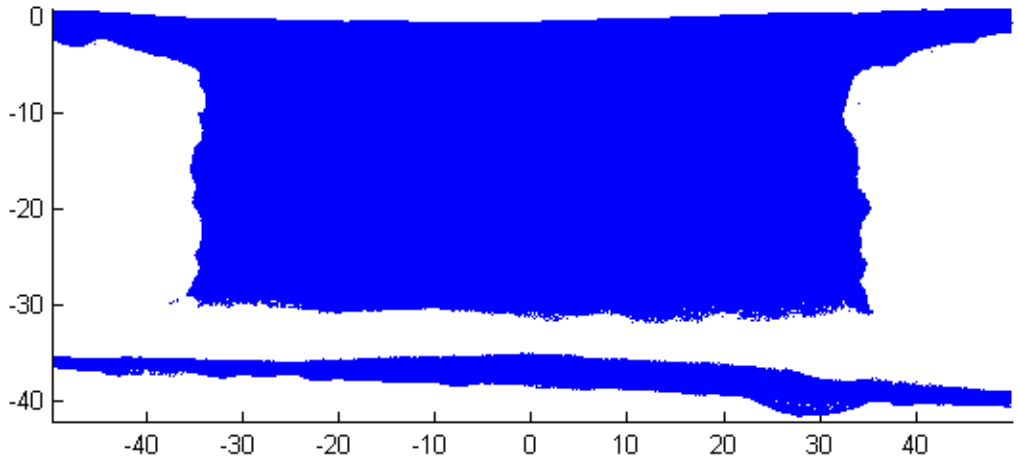


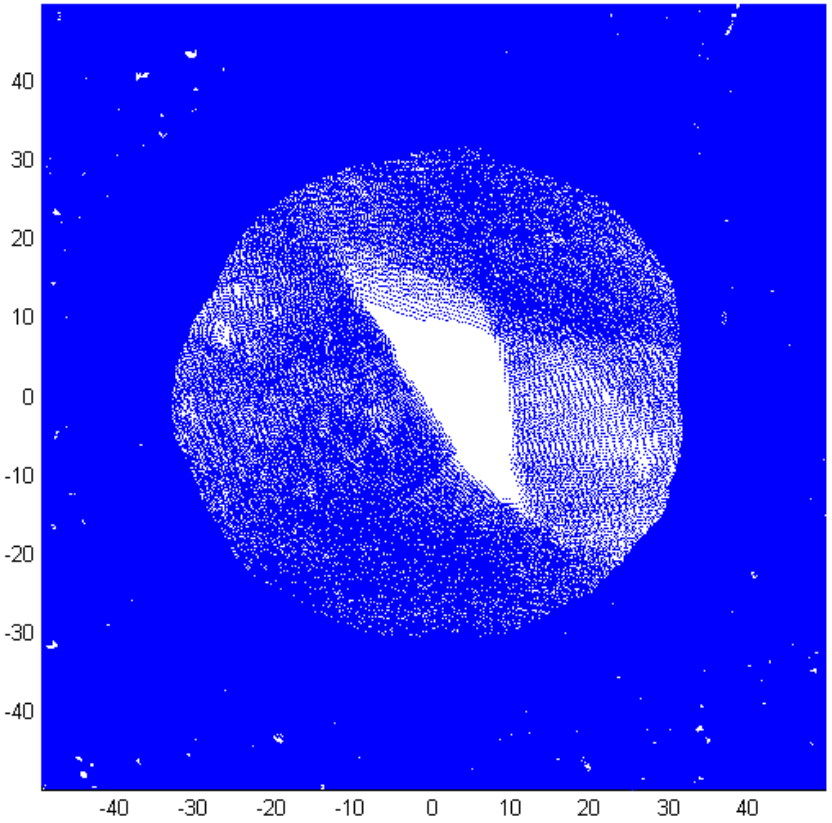


Rover Path Planned from Flyover Data

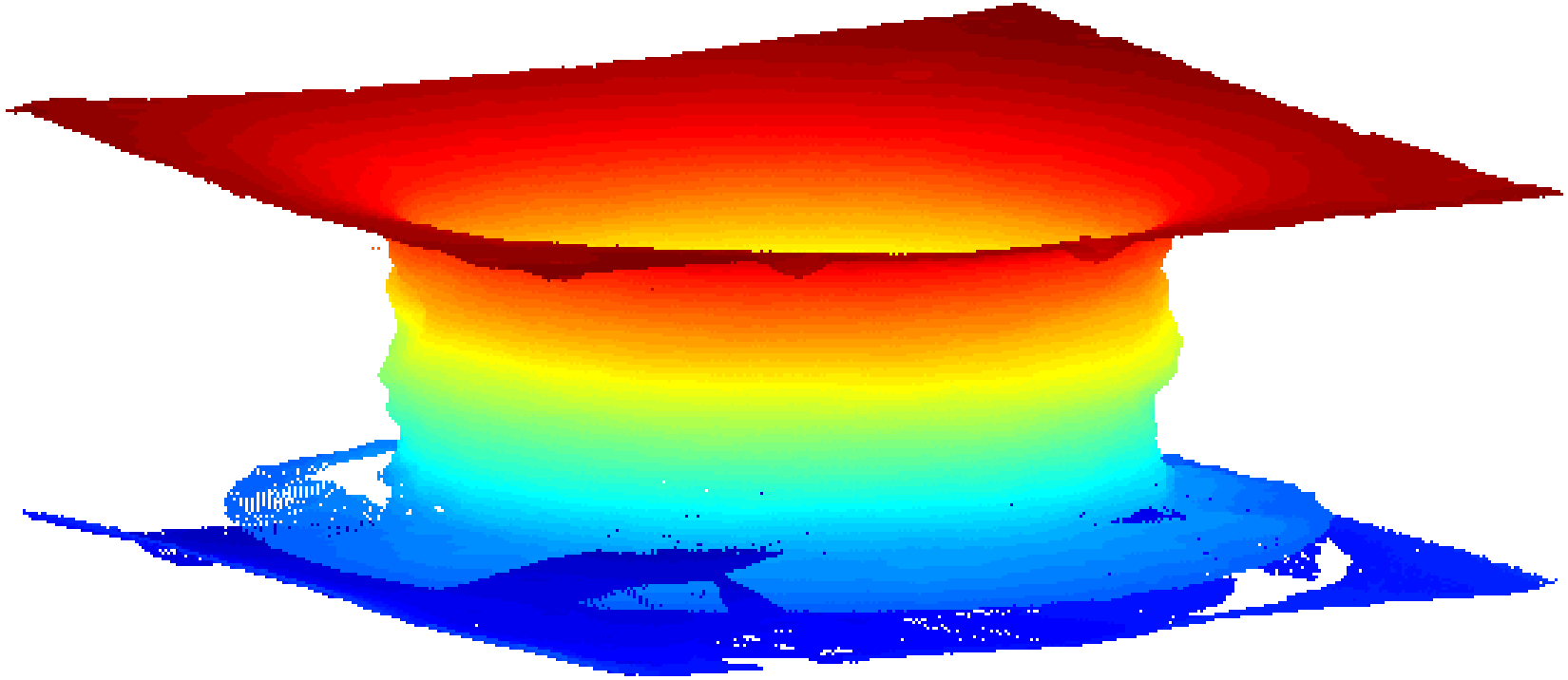


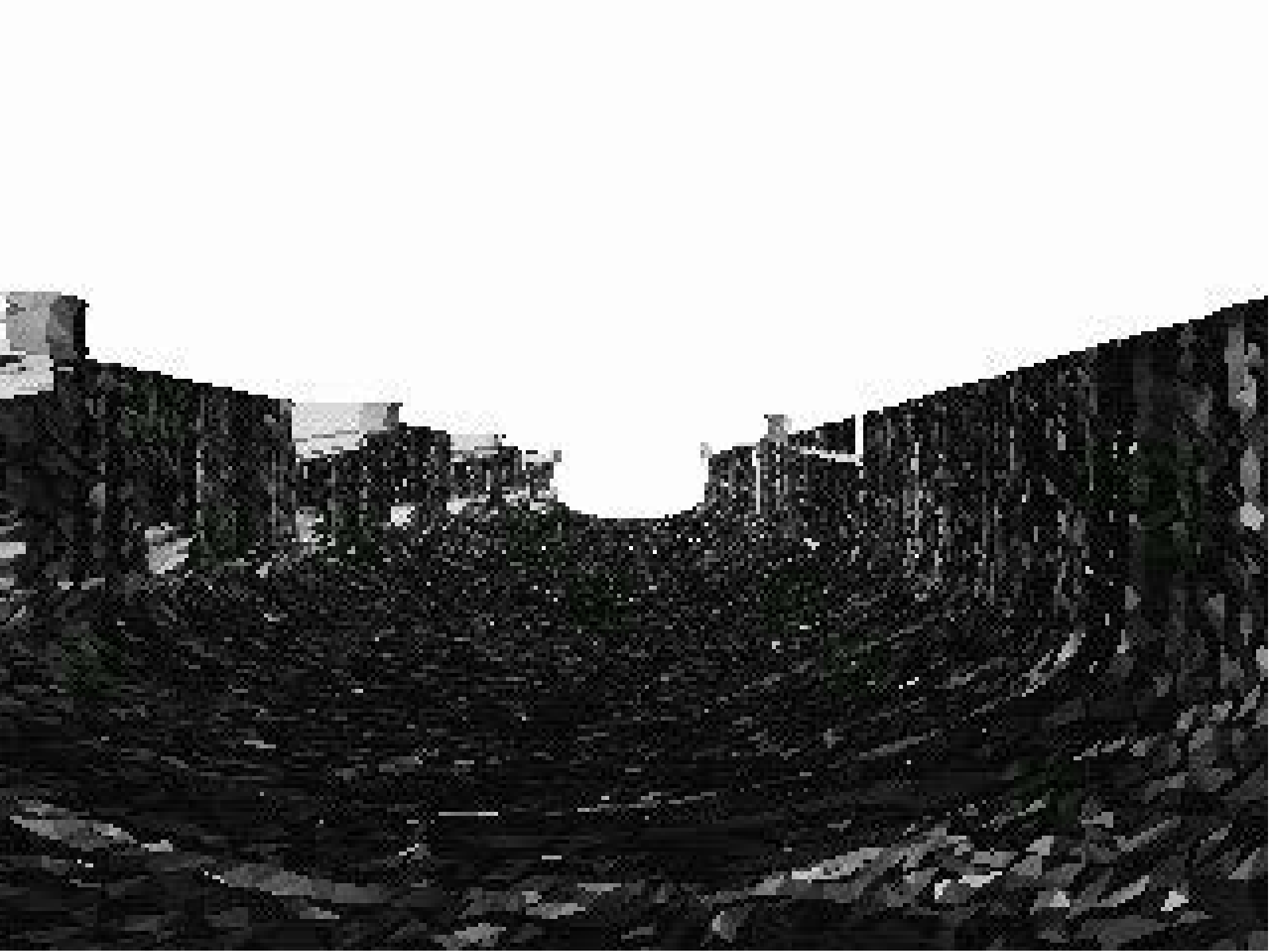
Rover Only Model

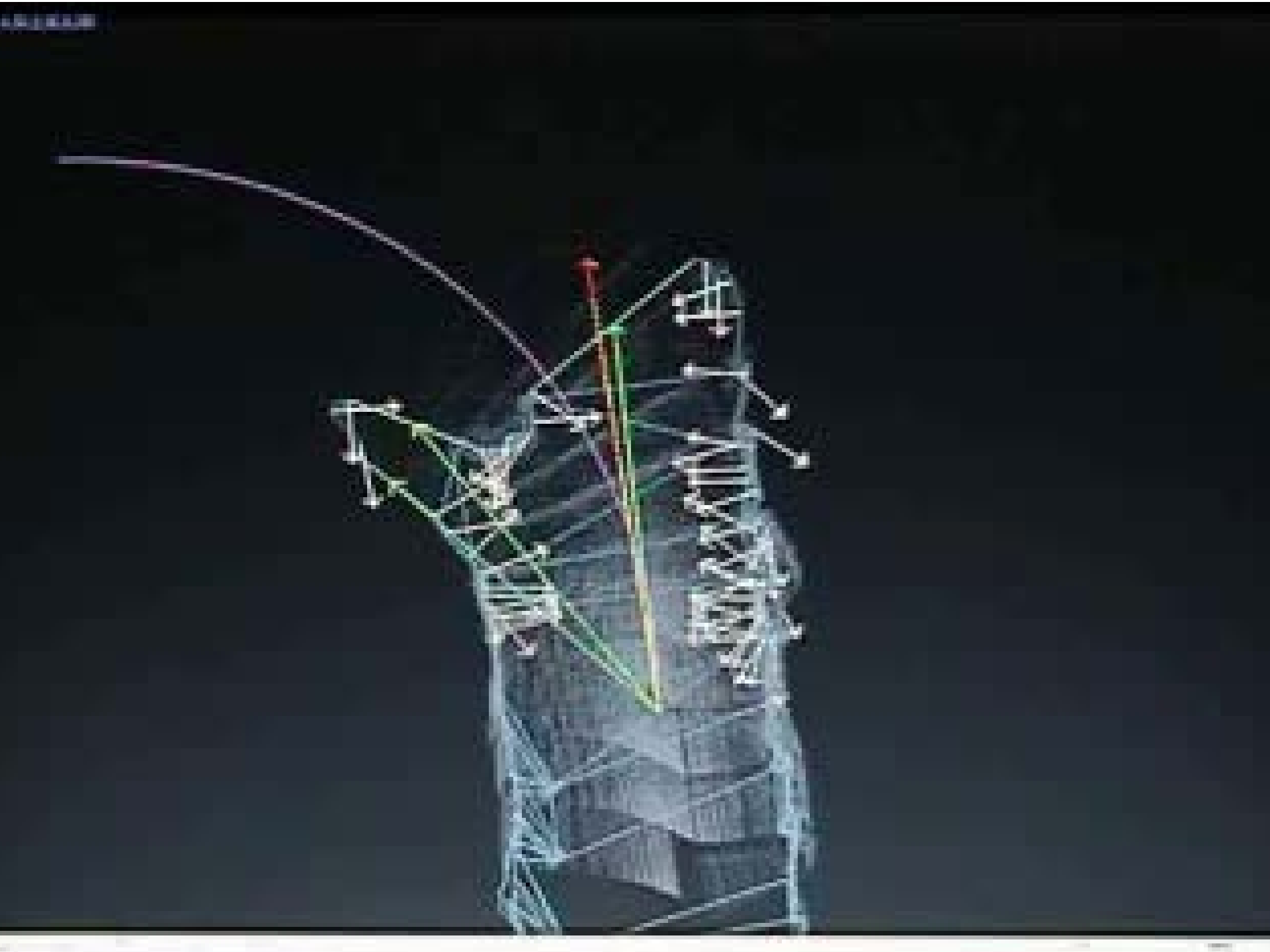




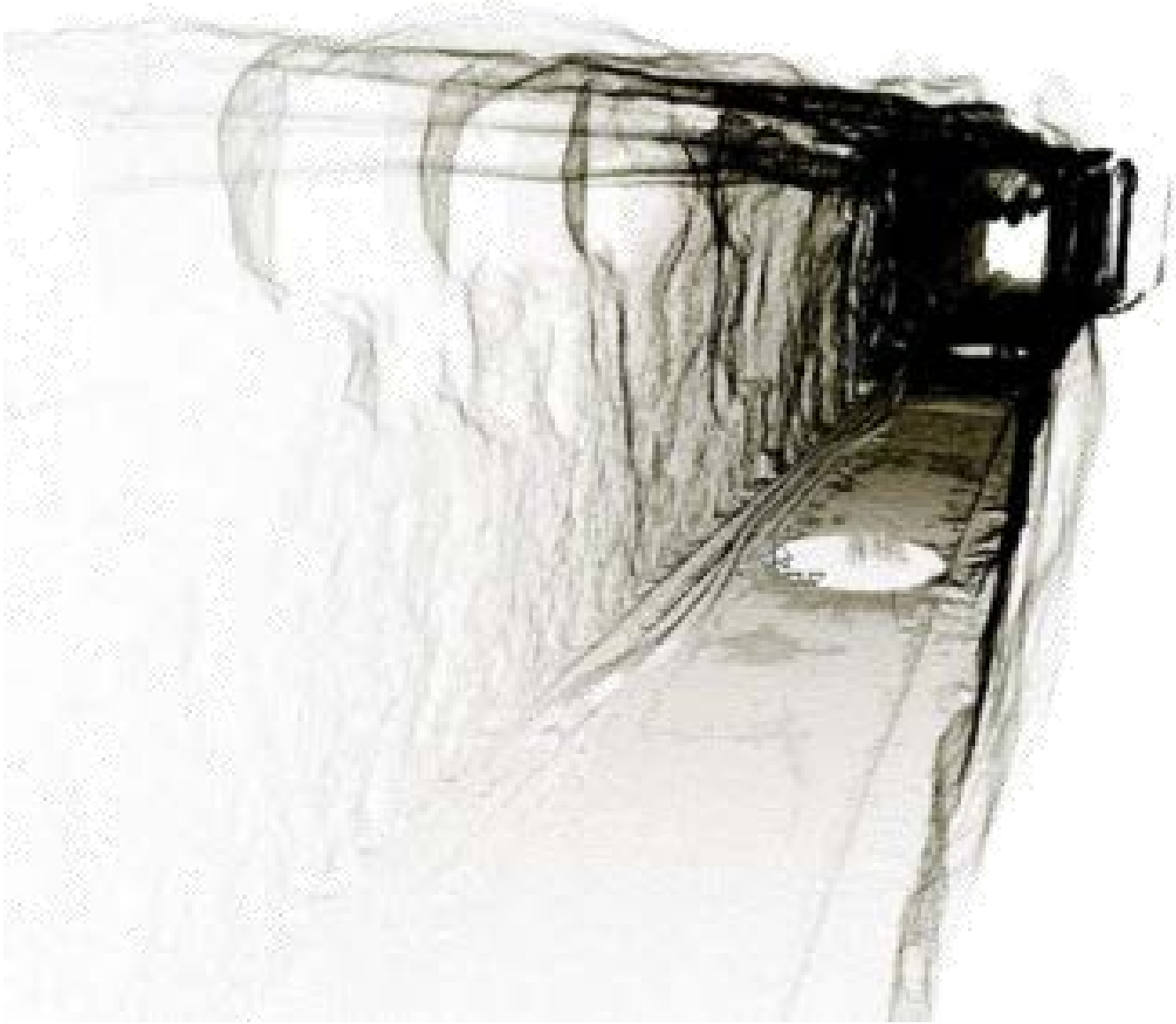
Hi-Res Flyover and Surface Model Showing Cave Entrance and Descent Route



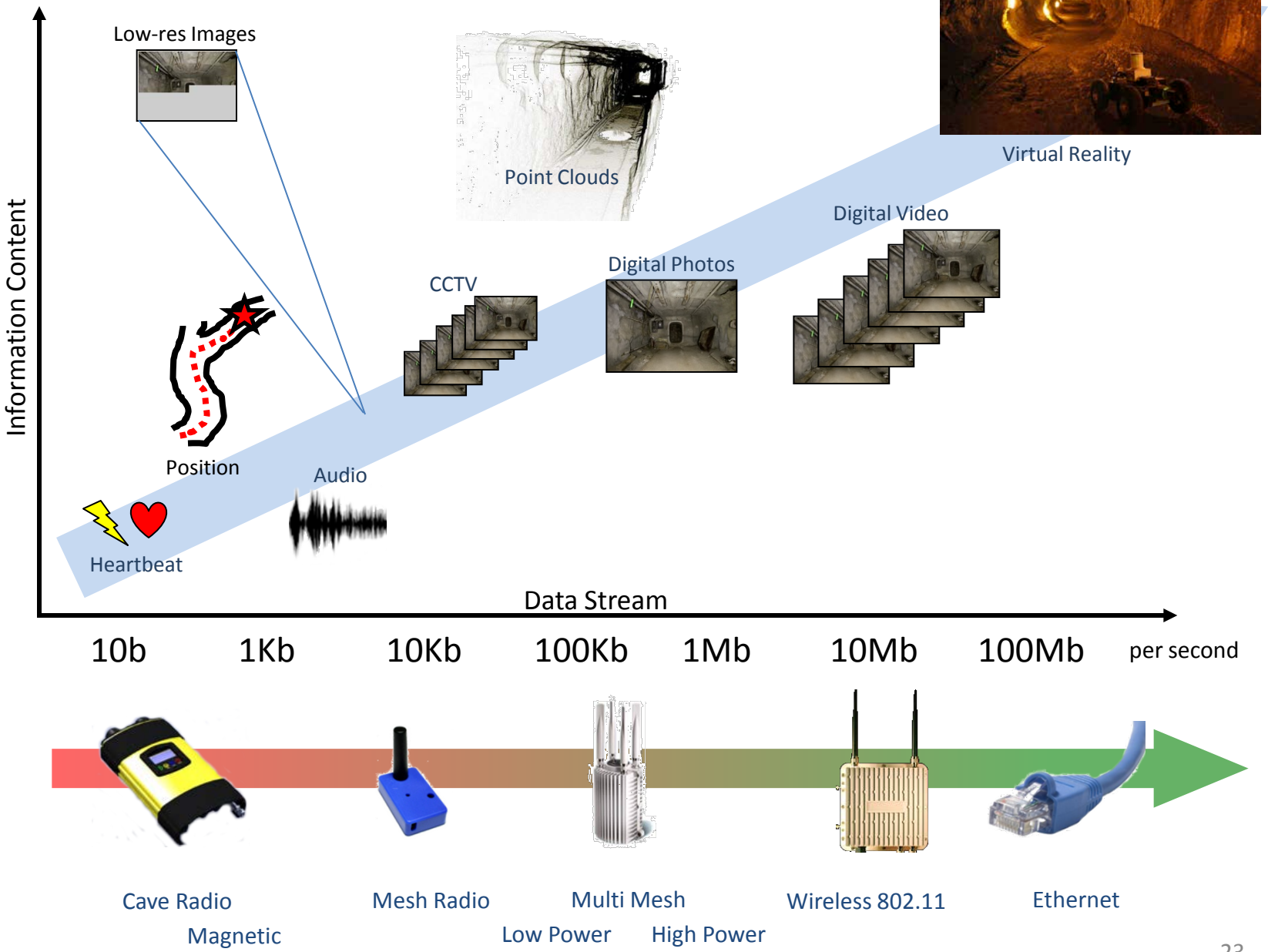


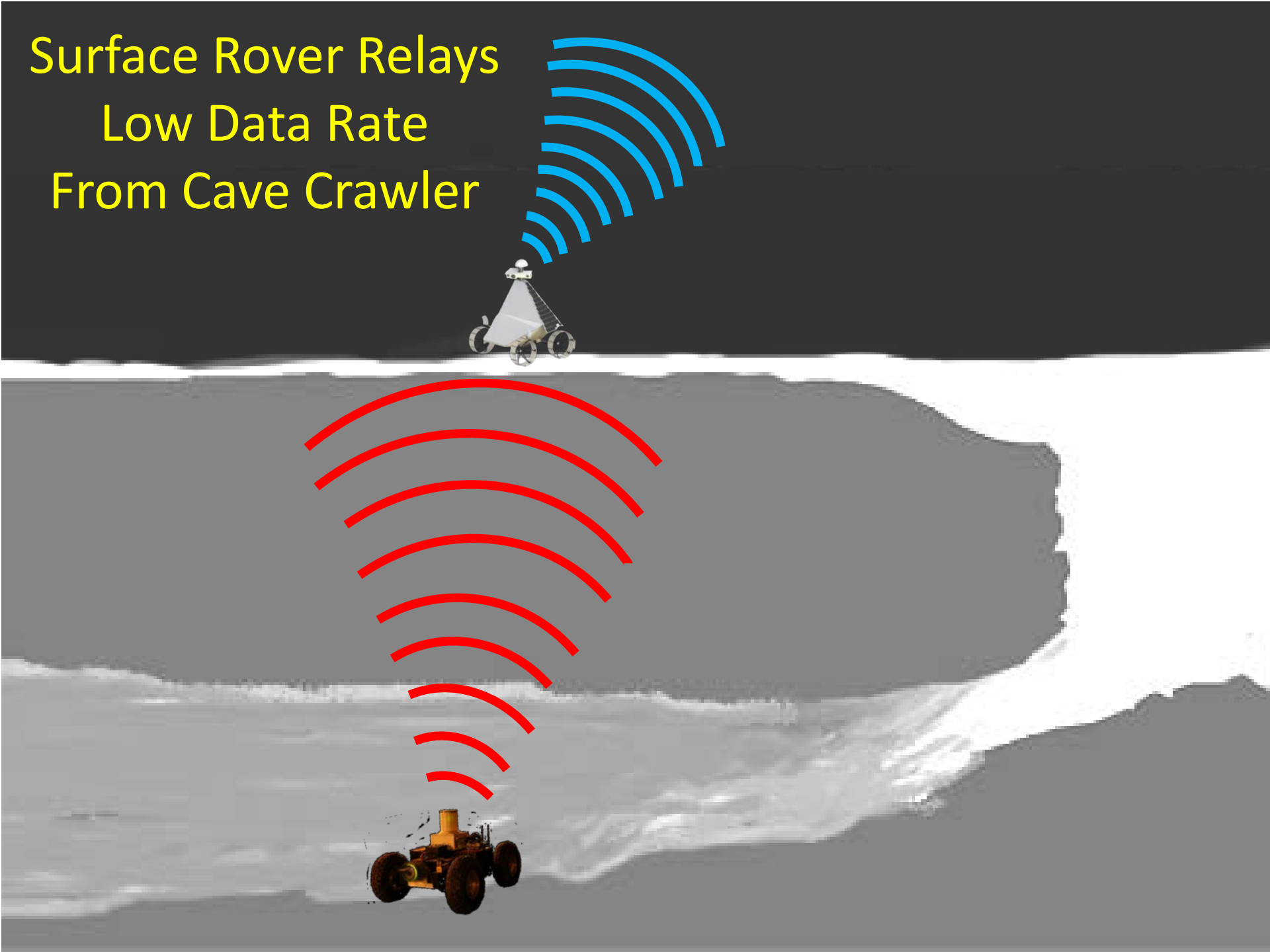


3D Spatial Model



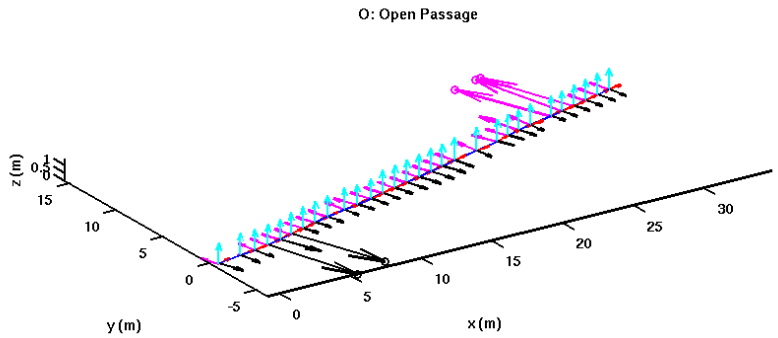
Virtualized Model


Low-res Images
Point Clouds
Virtual Reality
Digital Video
Digital Photos
CCTV
Position
Audio
Heartbeat
Information Content
Data Stream
10b
1Kb
10Kb
100Kb
1Mb
10Mb
100Mb
per second
Cave Radio
Magnetic
Mesh Radio
Multi Mesh
Low Power
High Power
Wireless 802.11
Ethernet


Surface Rover Relays
Low Data Rate
From Cave Crawler

Very Low Bandwidth

1. Heartbeat - Identification
2. Status - Stopped, On mission, Returning, Disabled
3. Location, orientation, distance traveled and route
4. Remaining battery capacity
5. Cross section information
6. Issue command
7. Send last image



Robot ID:	Explorer 4
Robot Status :	Good
Battery Voltage:	28.2 volts
Power Draw:	100 watts
Heading:	N 85 E ABS
Temp:	-10.5 C

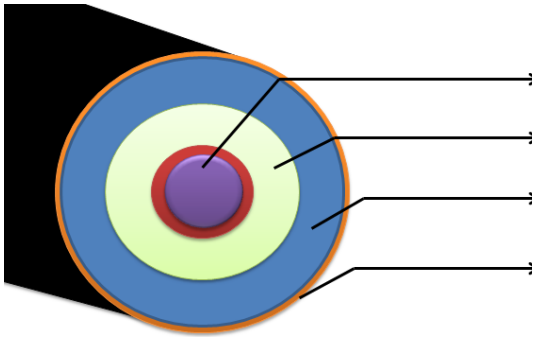
March 28, 2017 @	13:11:08
Excursion #:	2
Mission name:	Skylight
Distance completed:	932 m
Distance to go:	200 m
Start time:	12:15:06

Experimental Mine Exploration With Minimal Comm

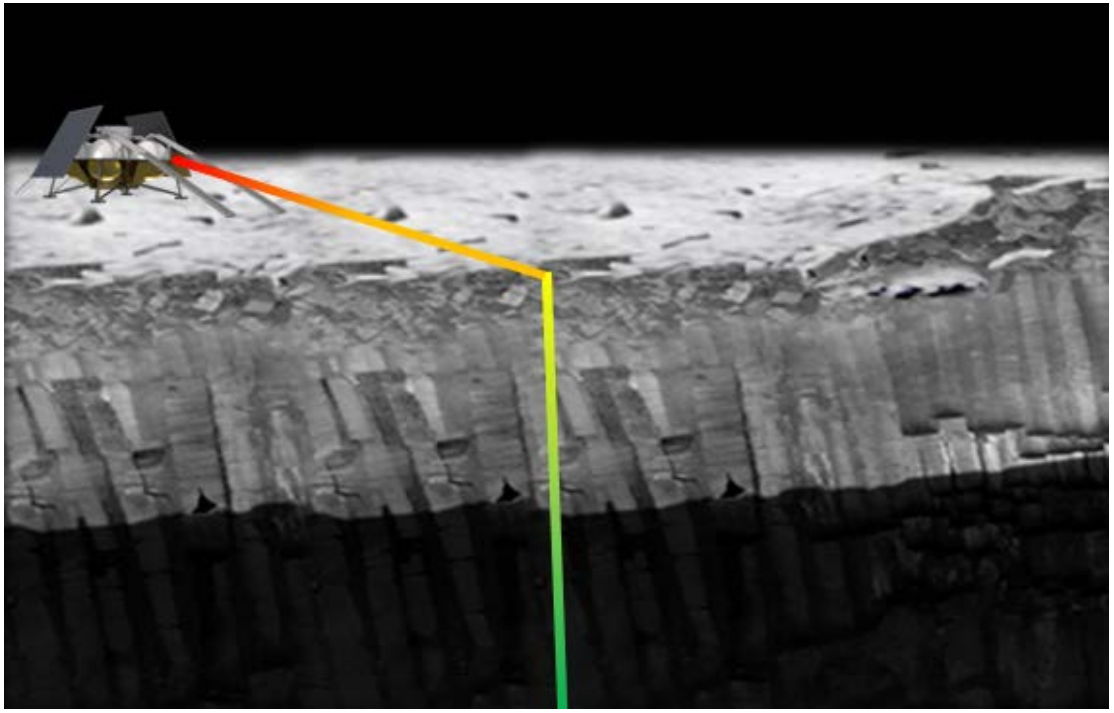
- Data rate during operation is like Morse Code

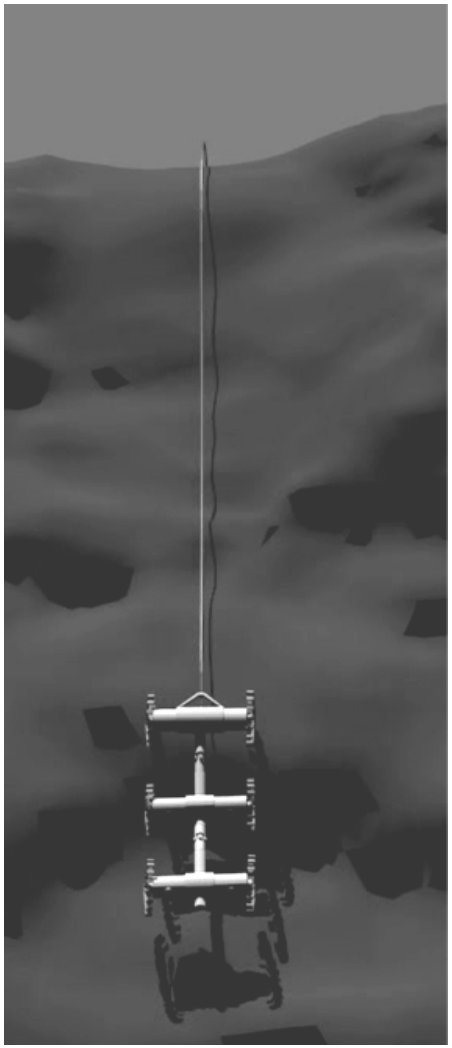
- Right window is operator model consisting of location, width/height, branching option, status and vital statistics.
- Left window is intermittent snapshot experienced by rover, but inaccessible to operators. Images are stored during cave sortie, then transmitted after return to high-band comm node.
- Route is out-and-back on “P-shaped” route passing 43 possible branches traveling about 600 meters

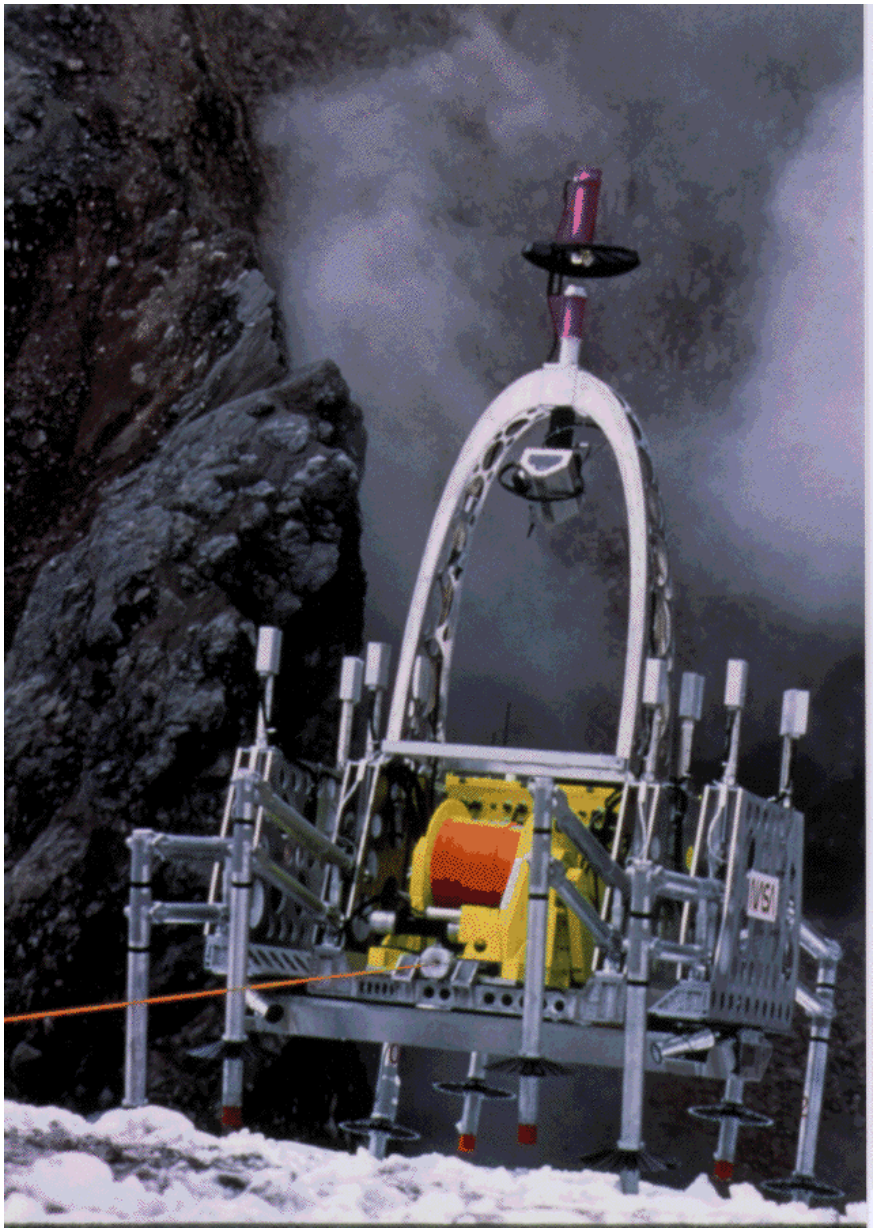
Tethered Rappel

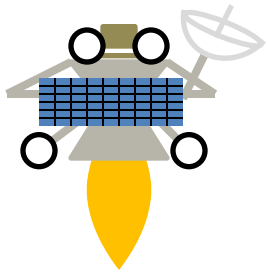


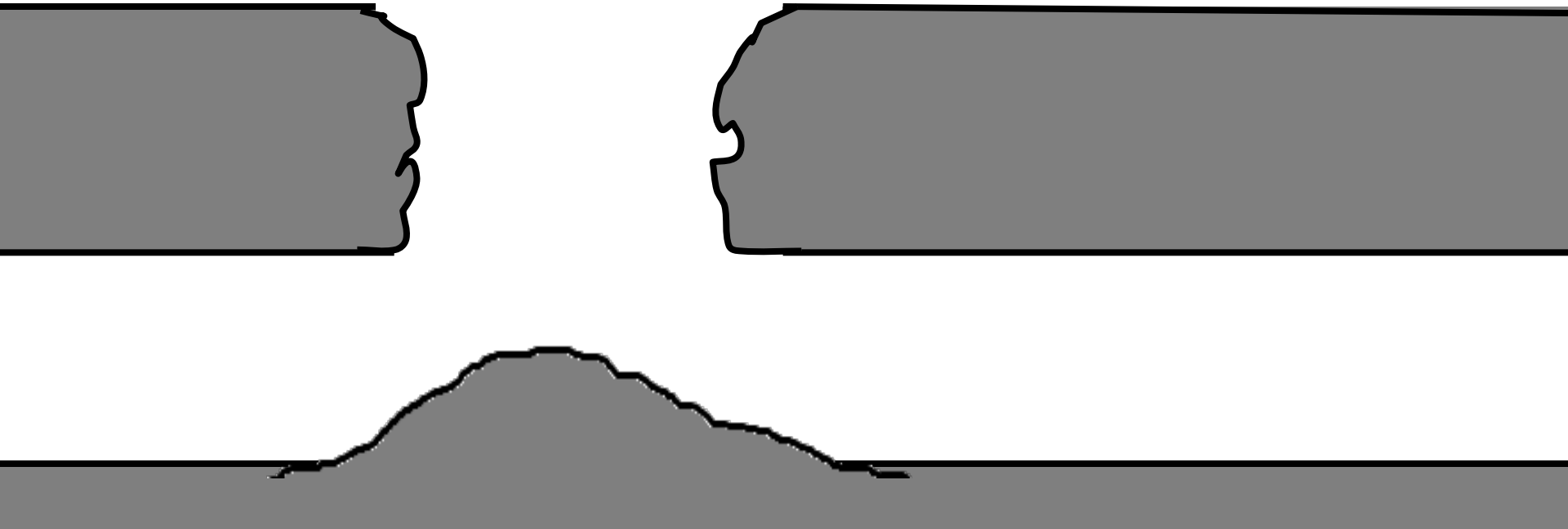
Power
Communication
Strength
Abrasion

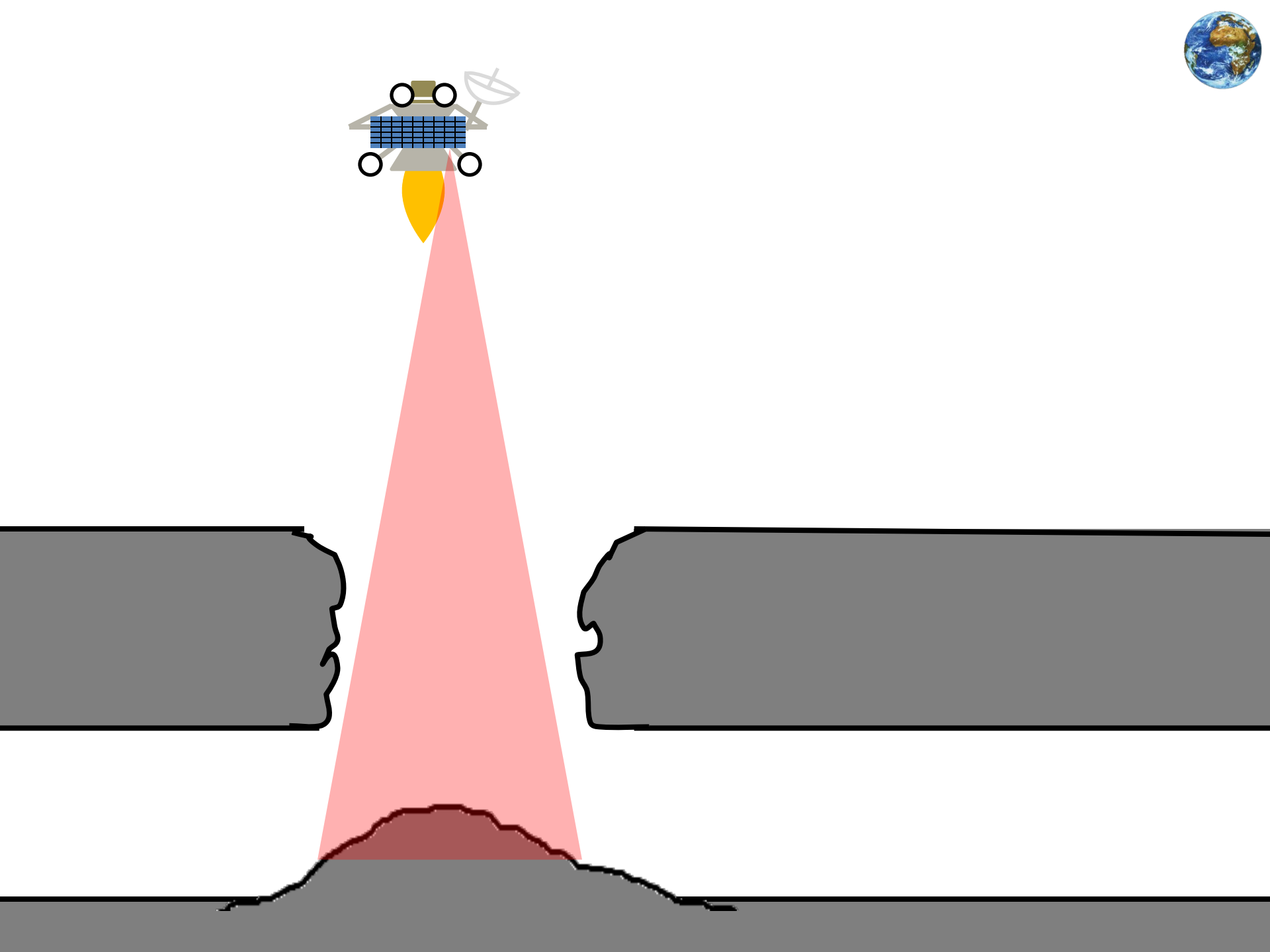


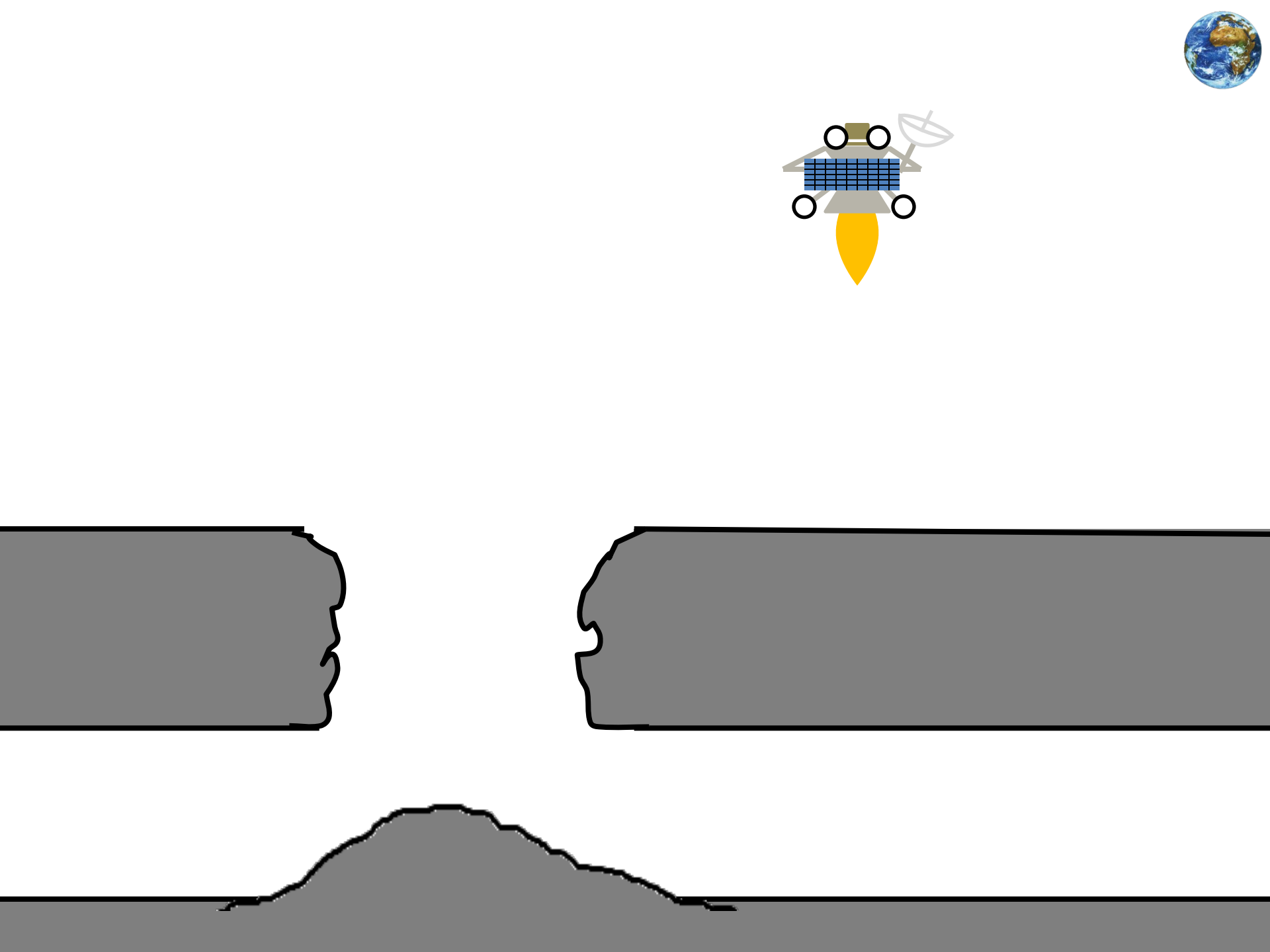


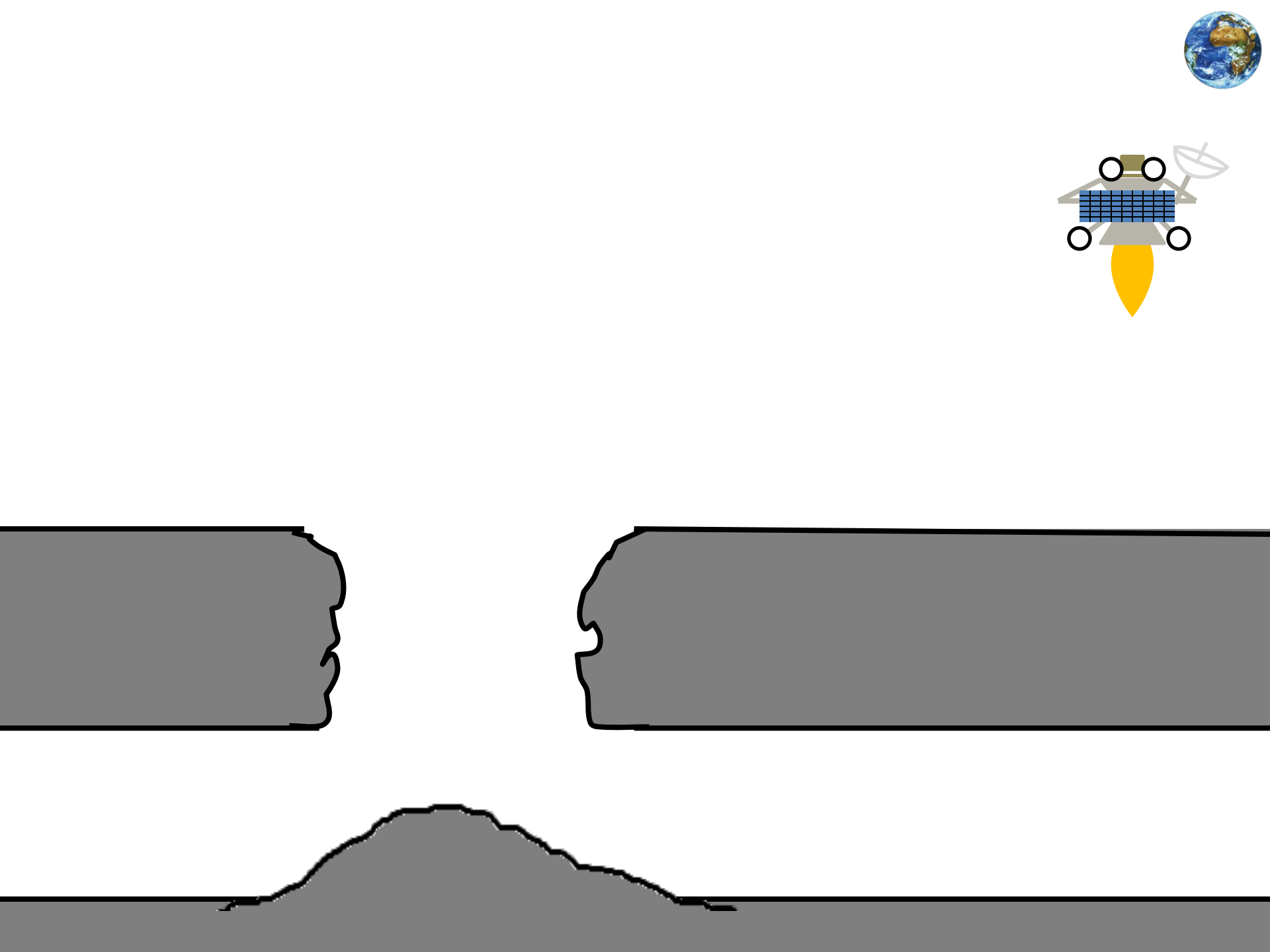


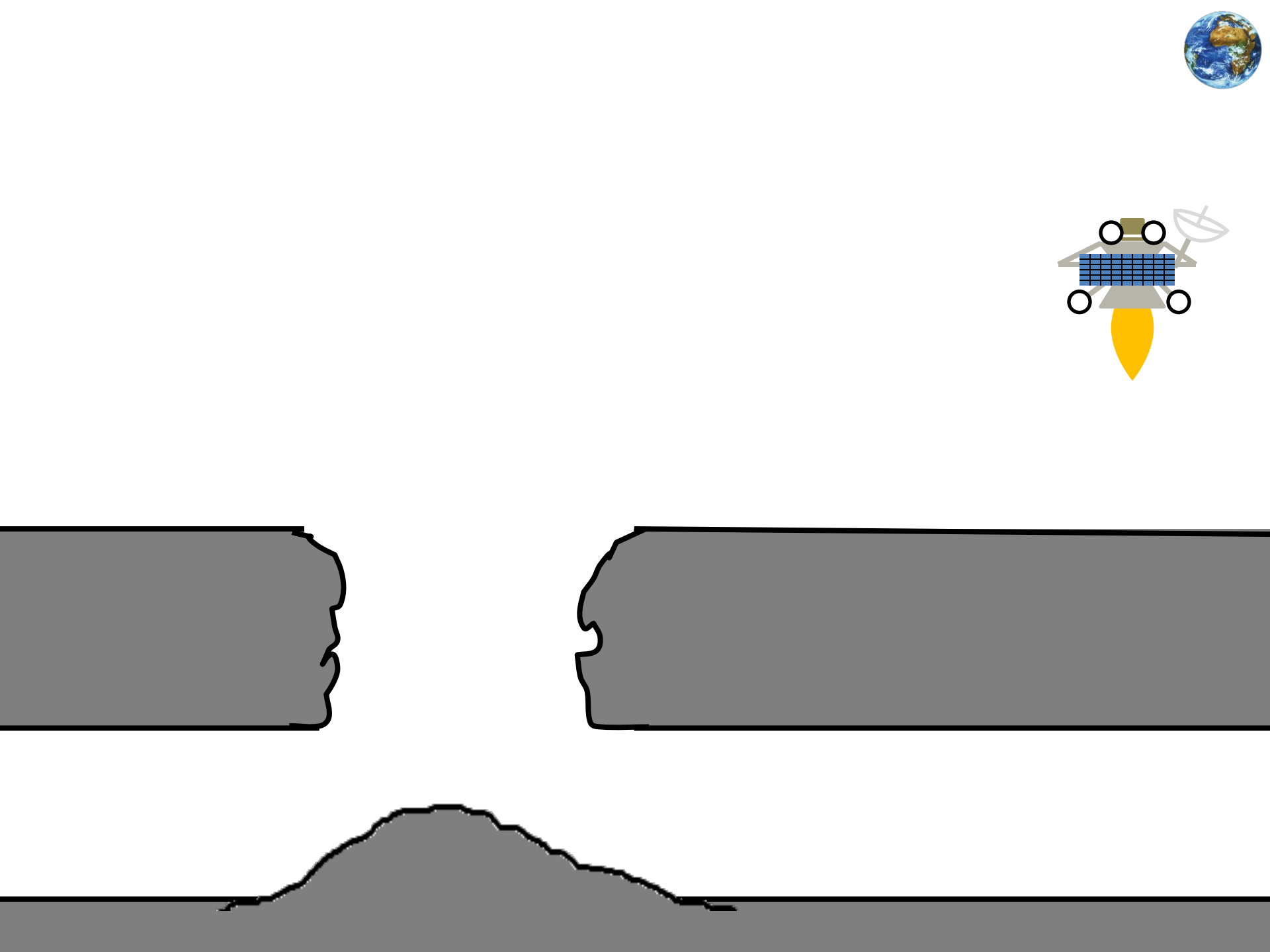


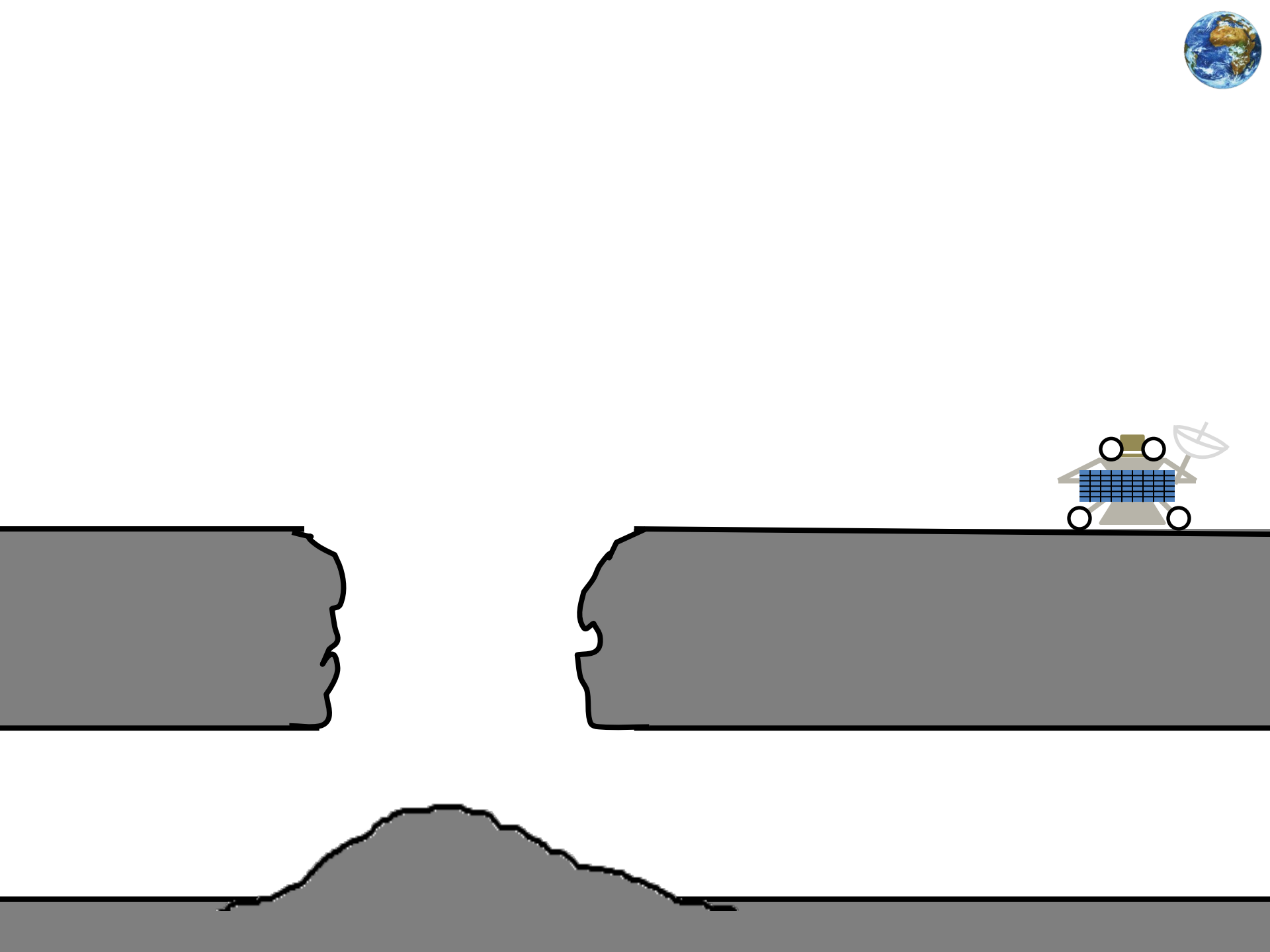


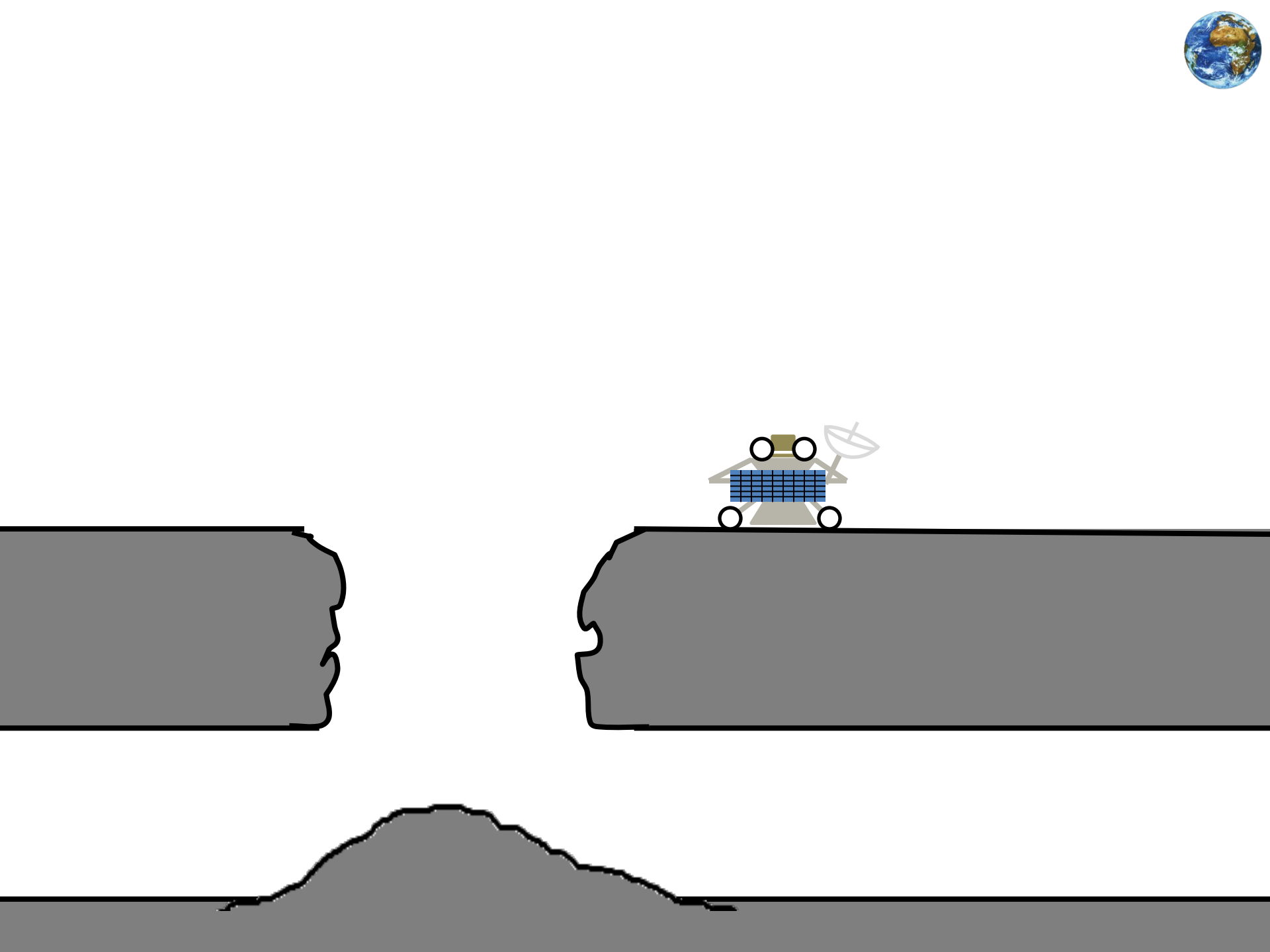


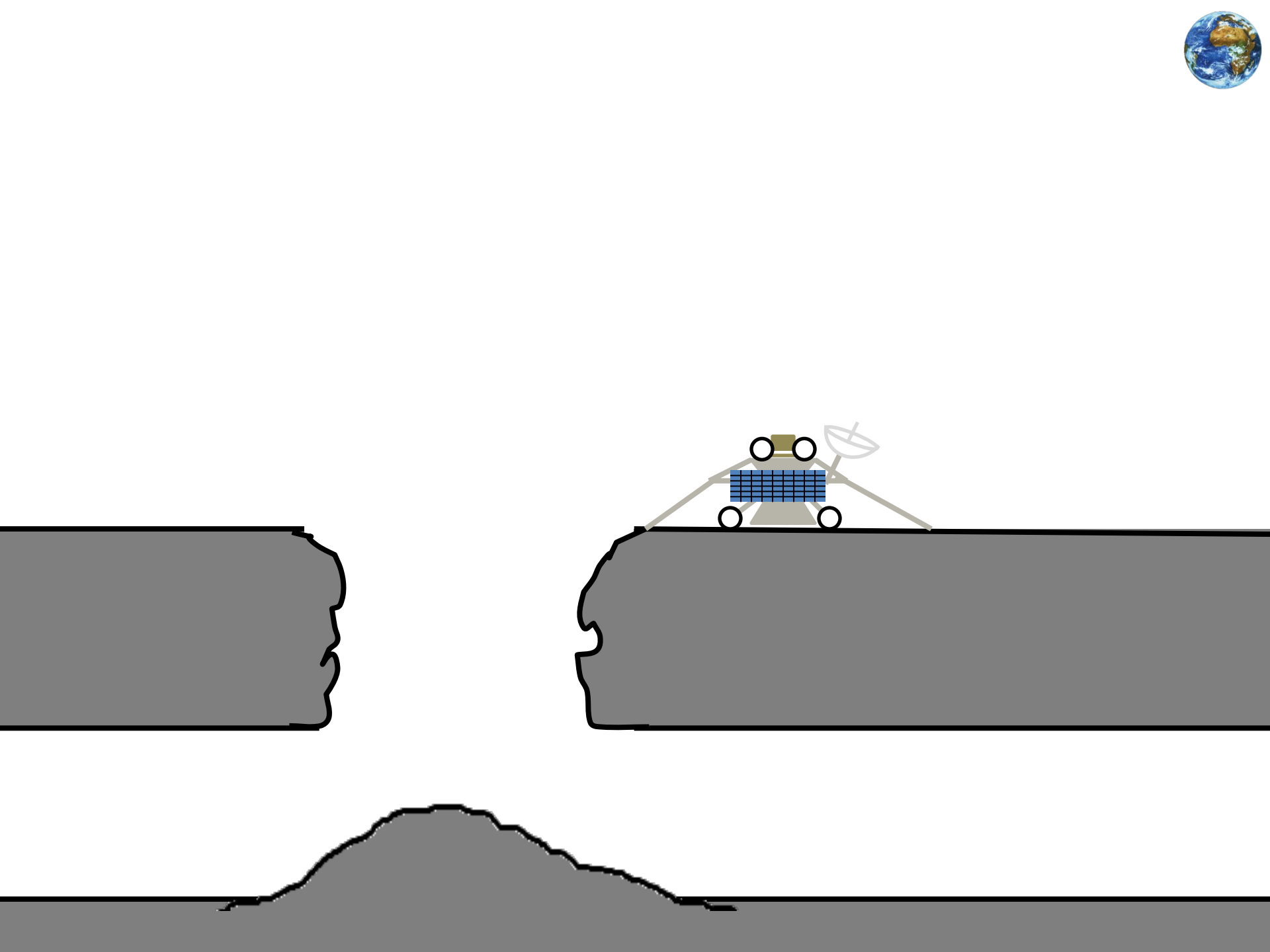


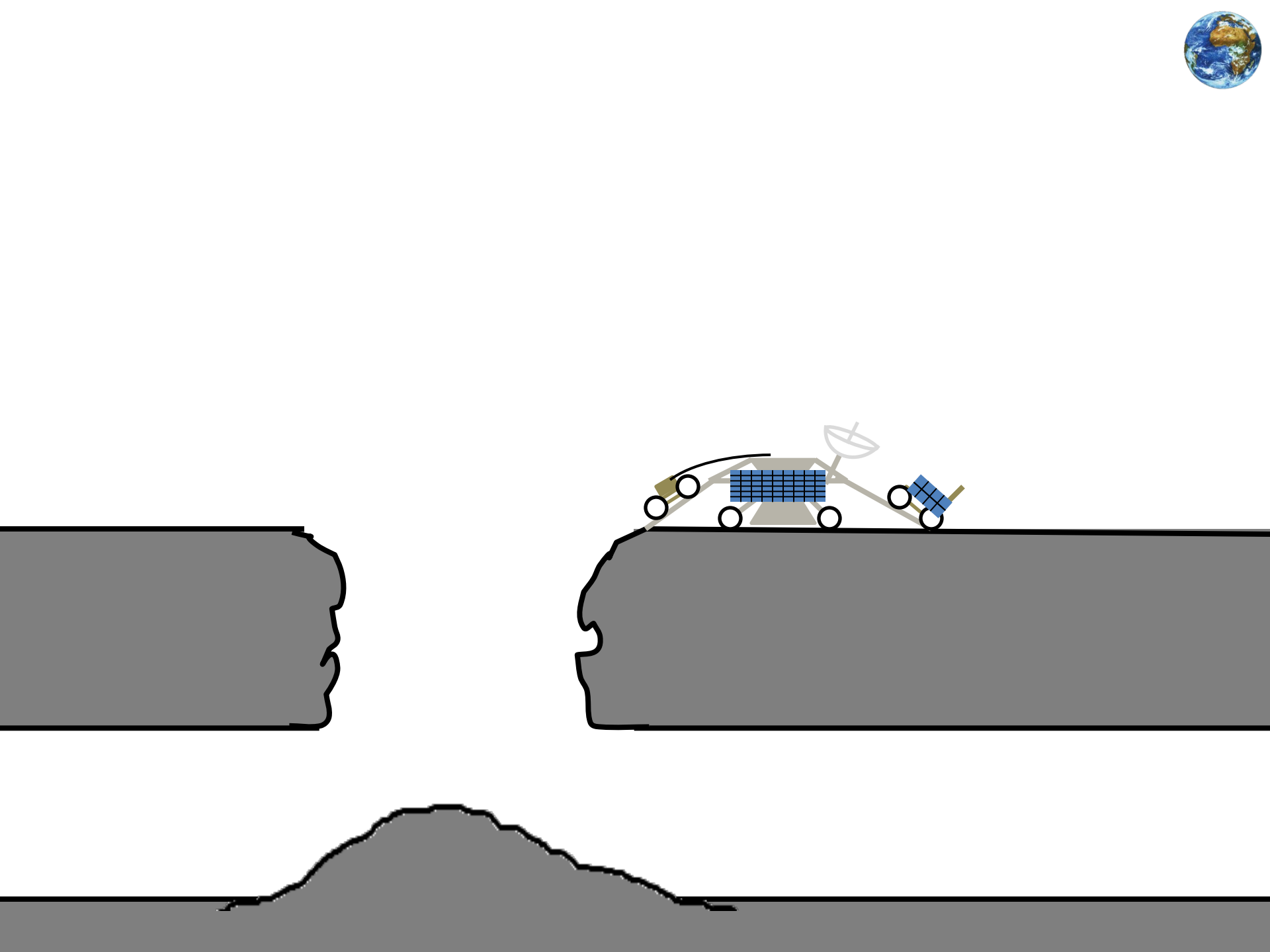


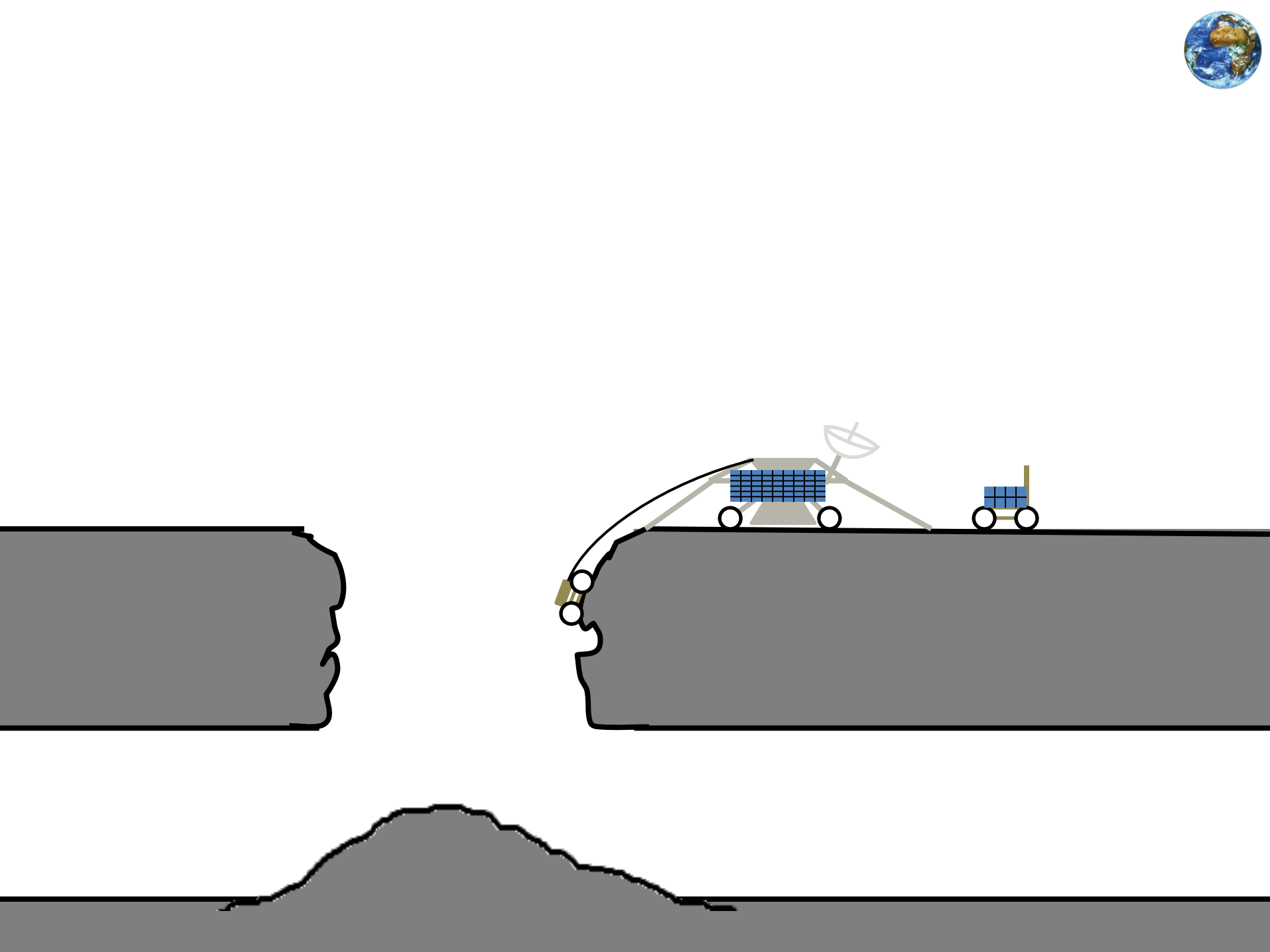


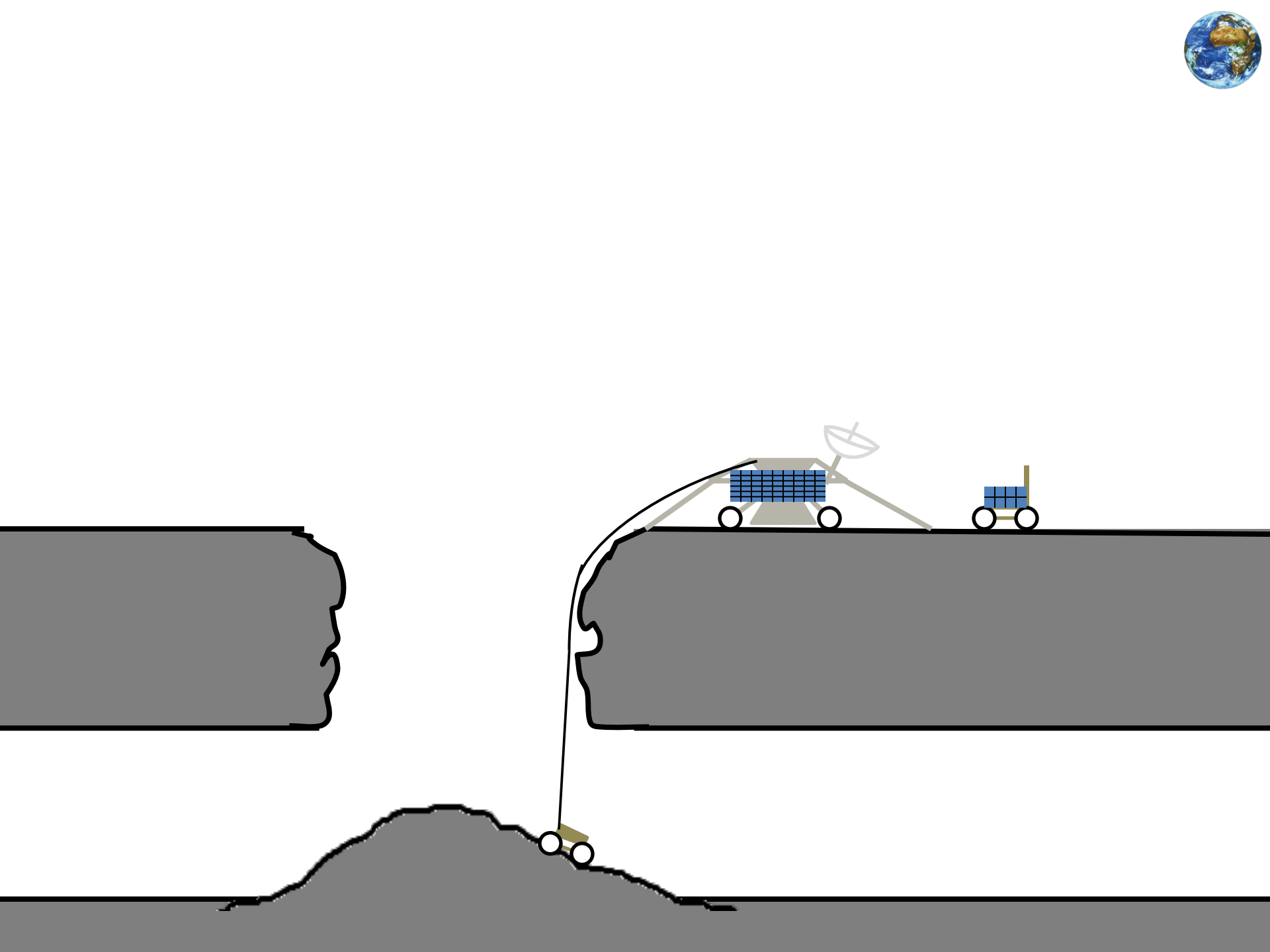


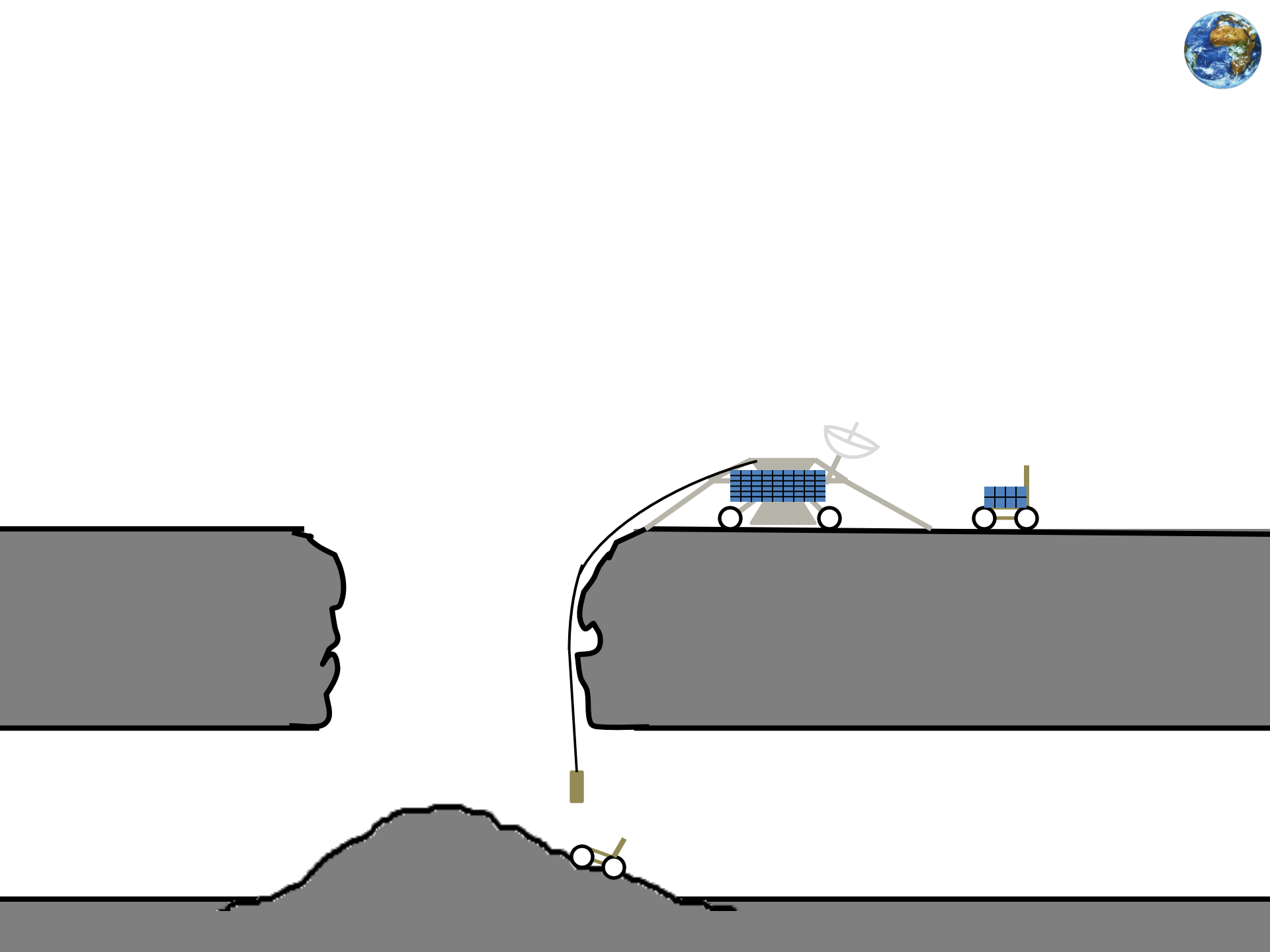


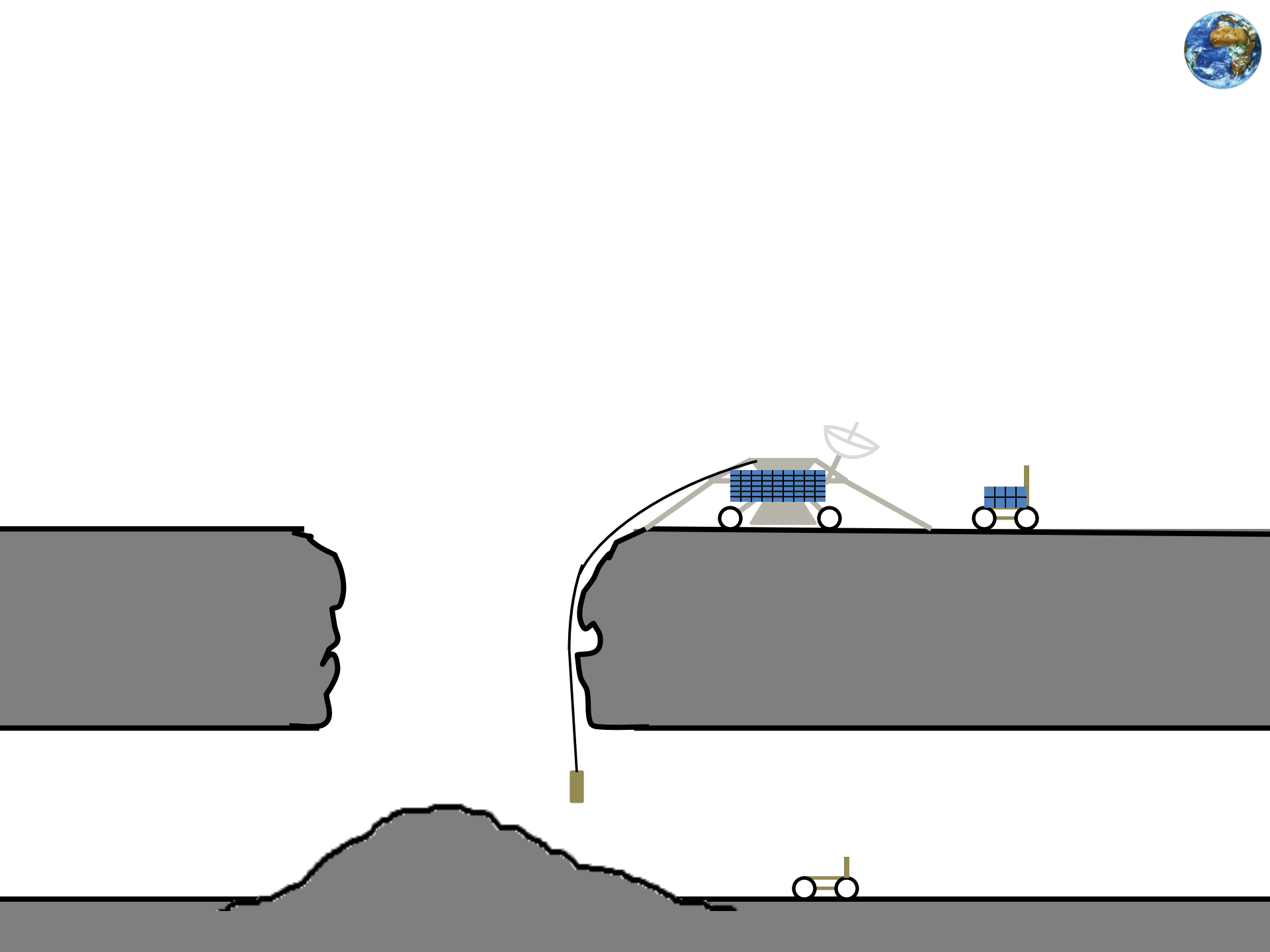


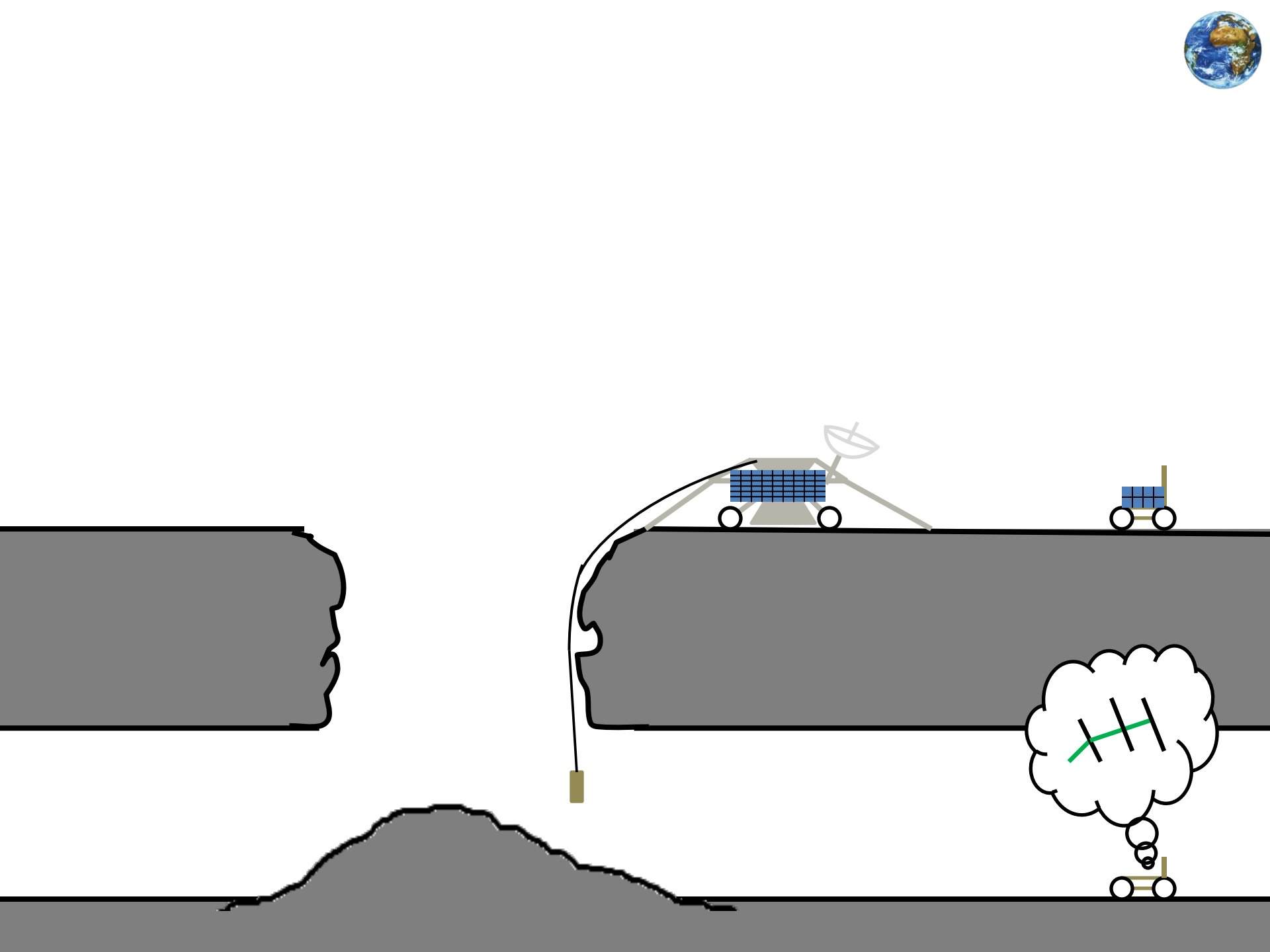


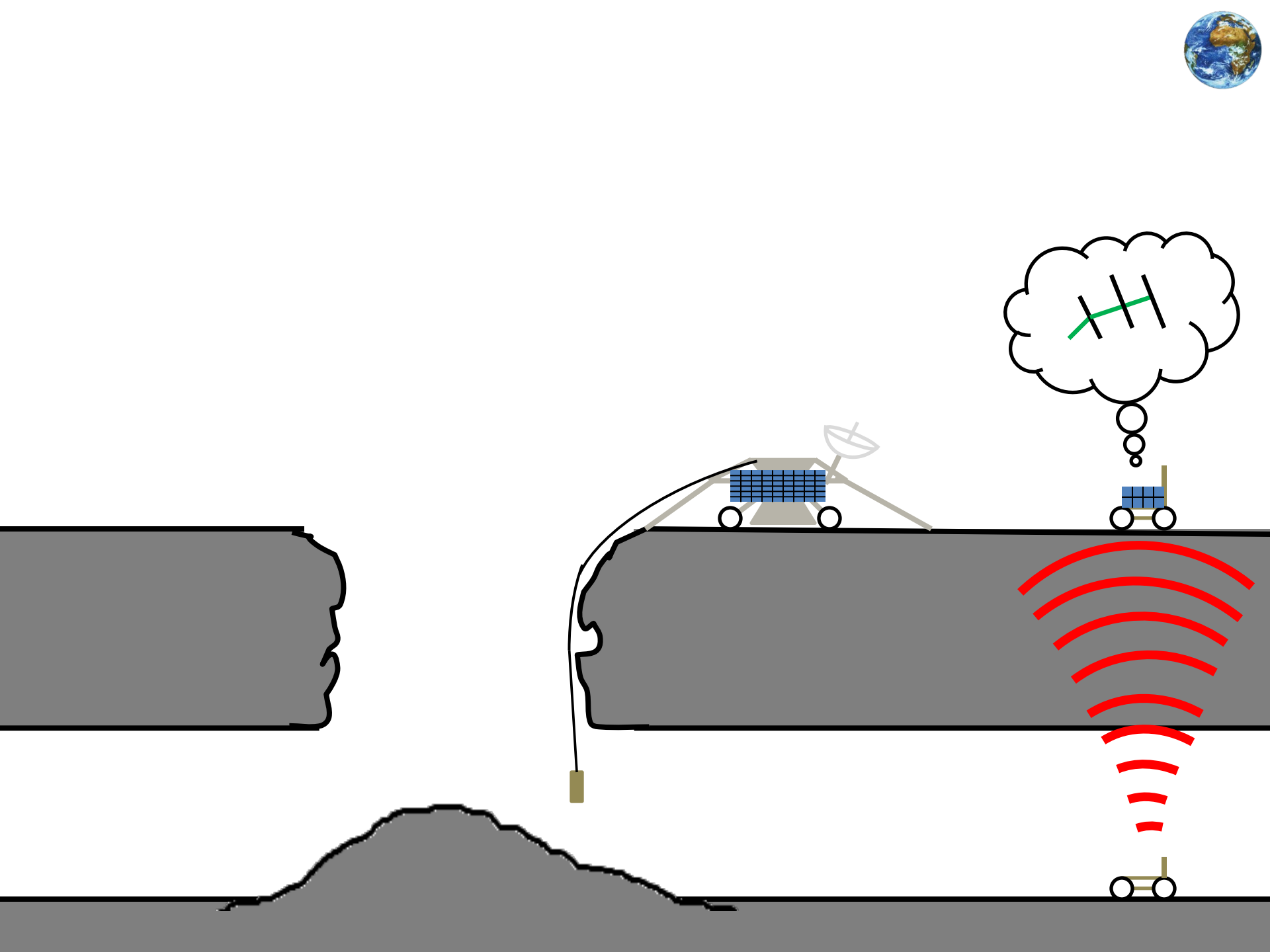


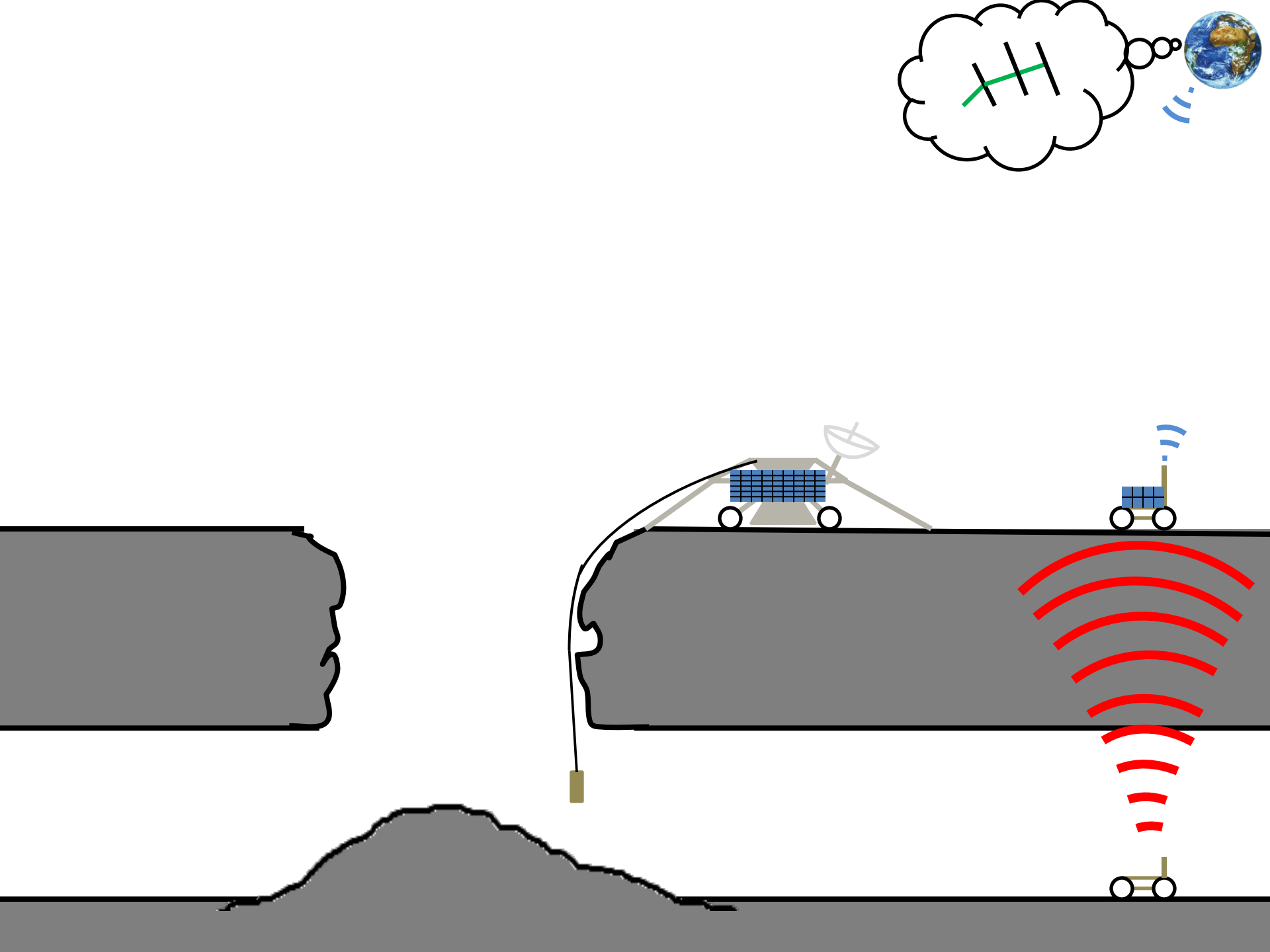


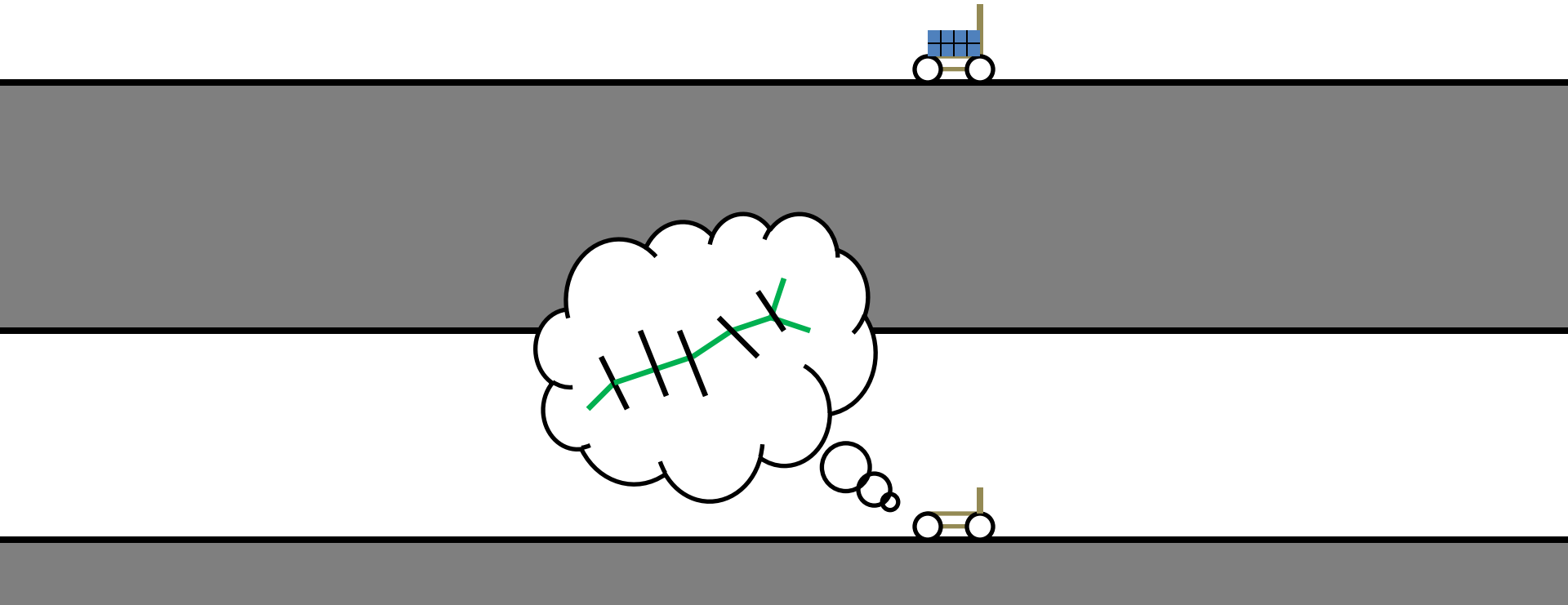


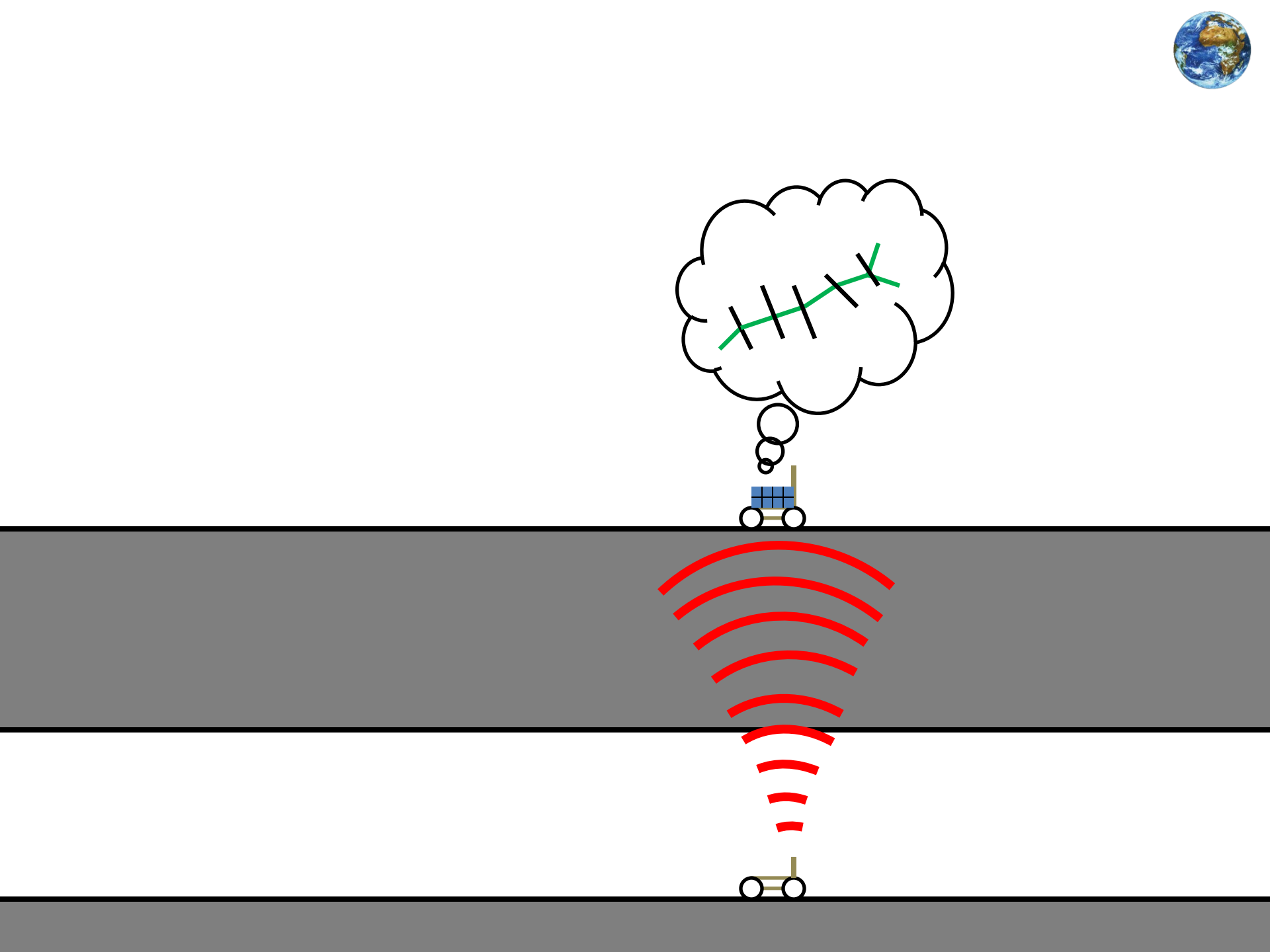


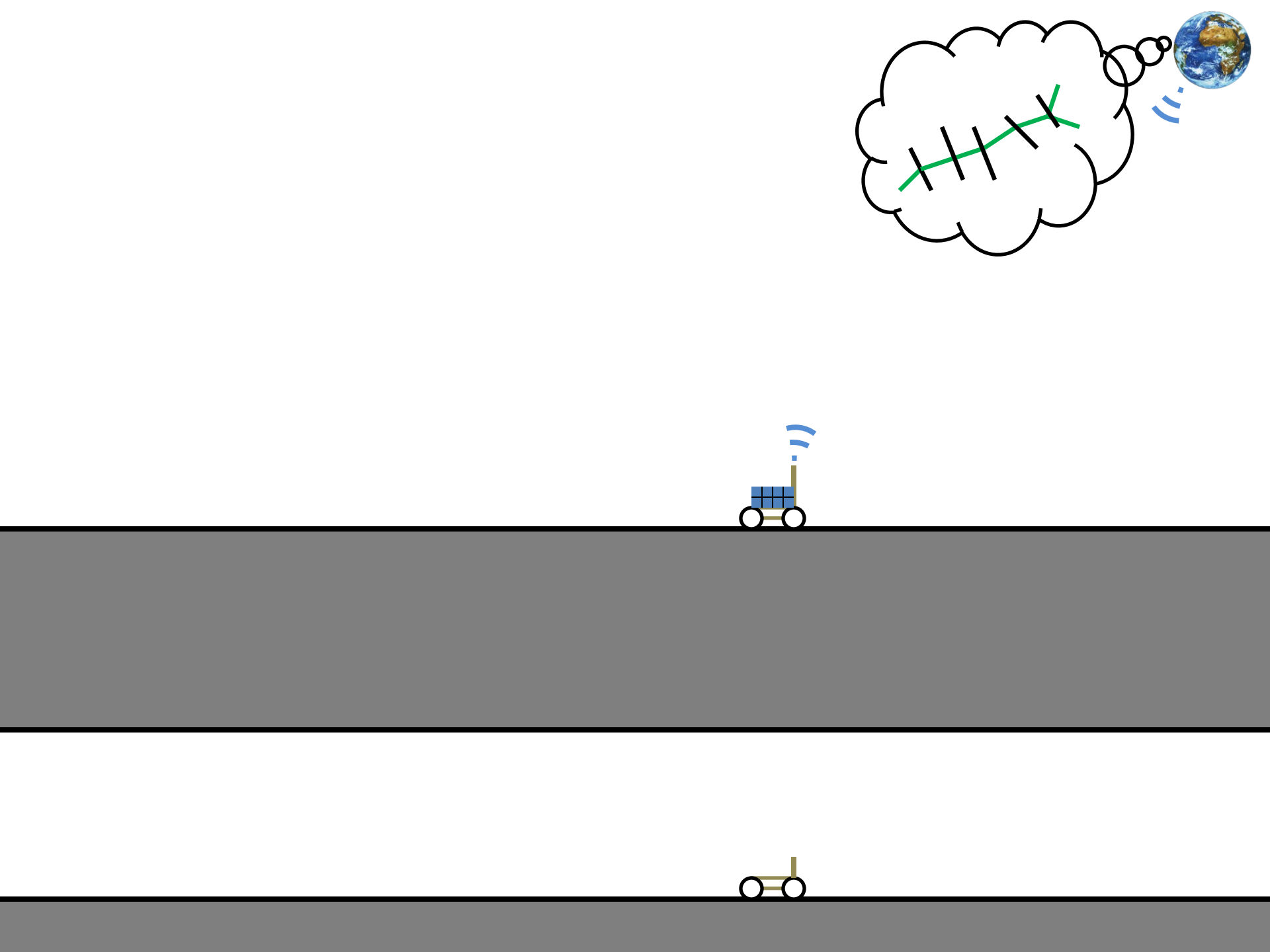


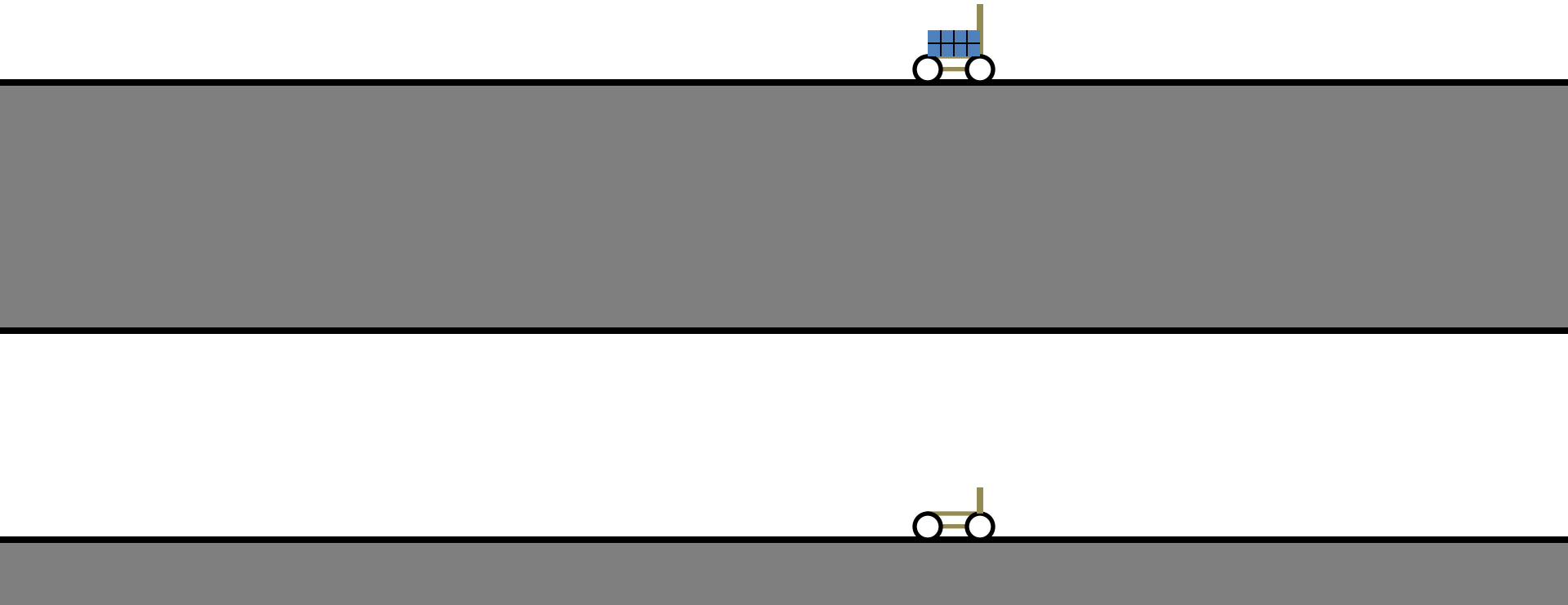


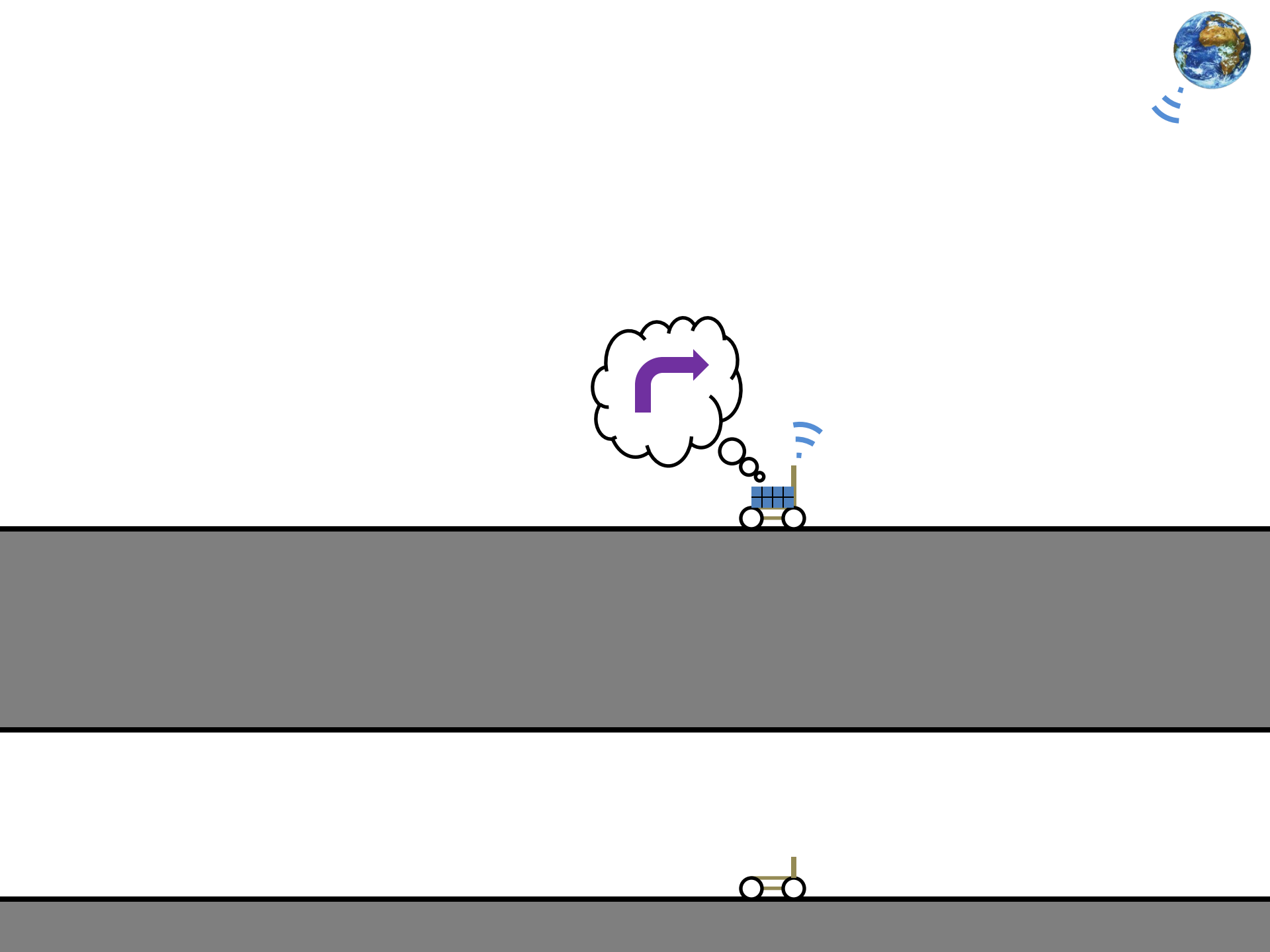


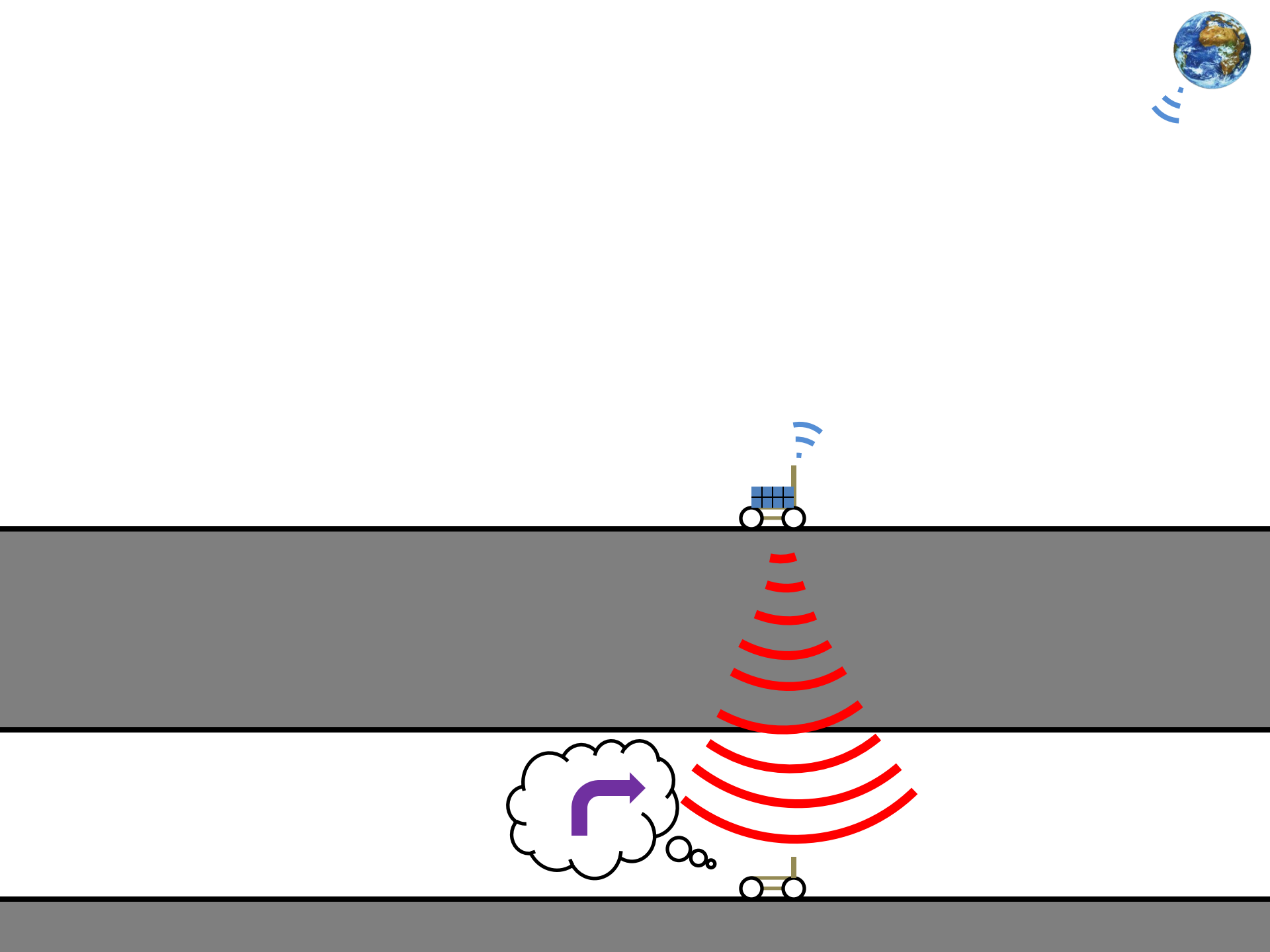


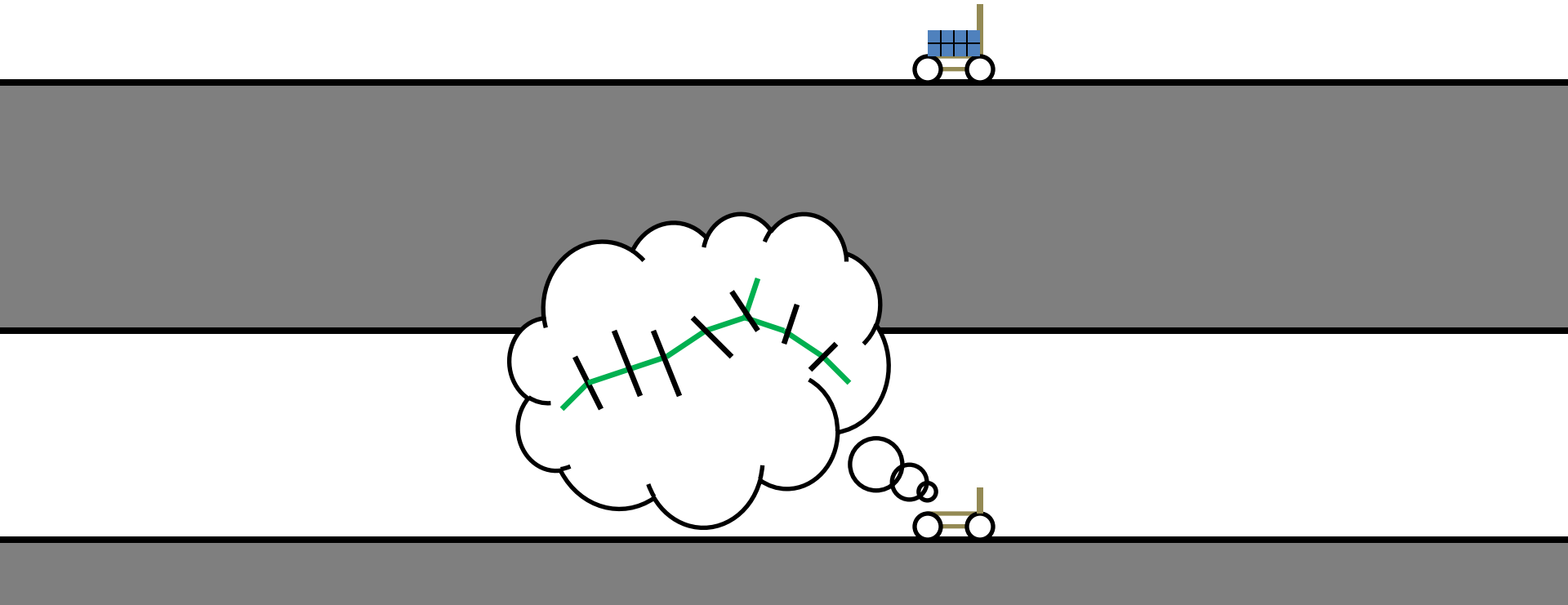


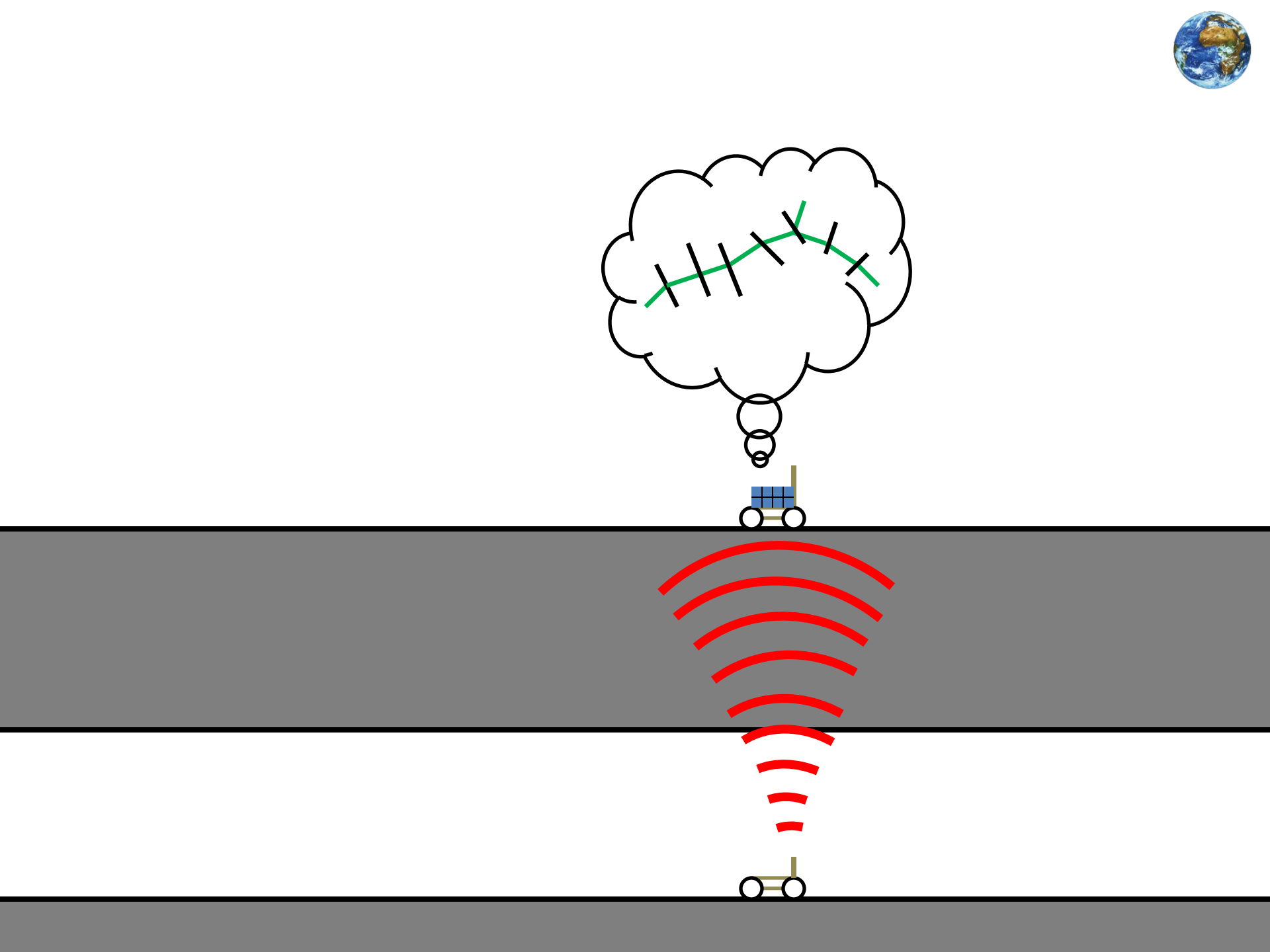


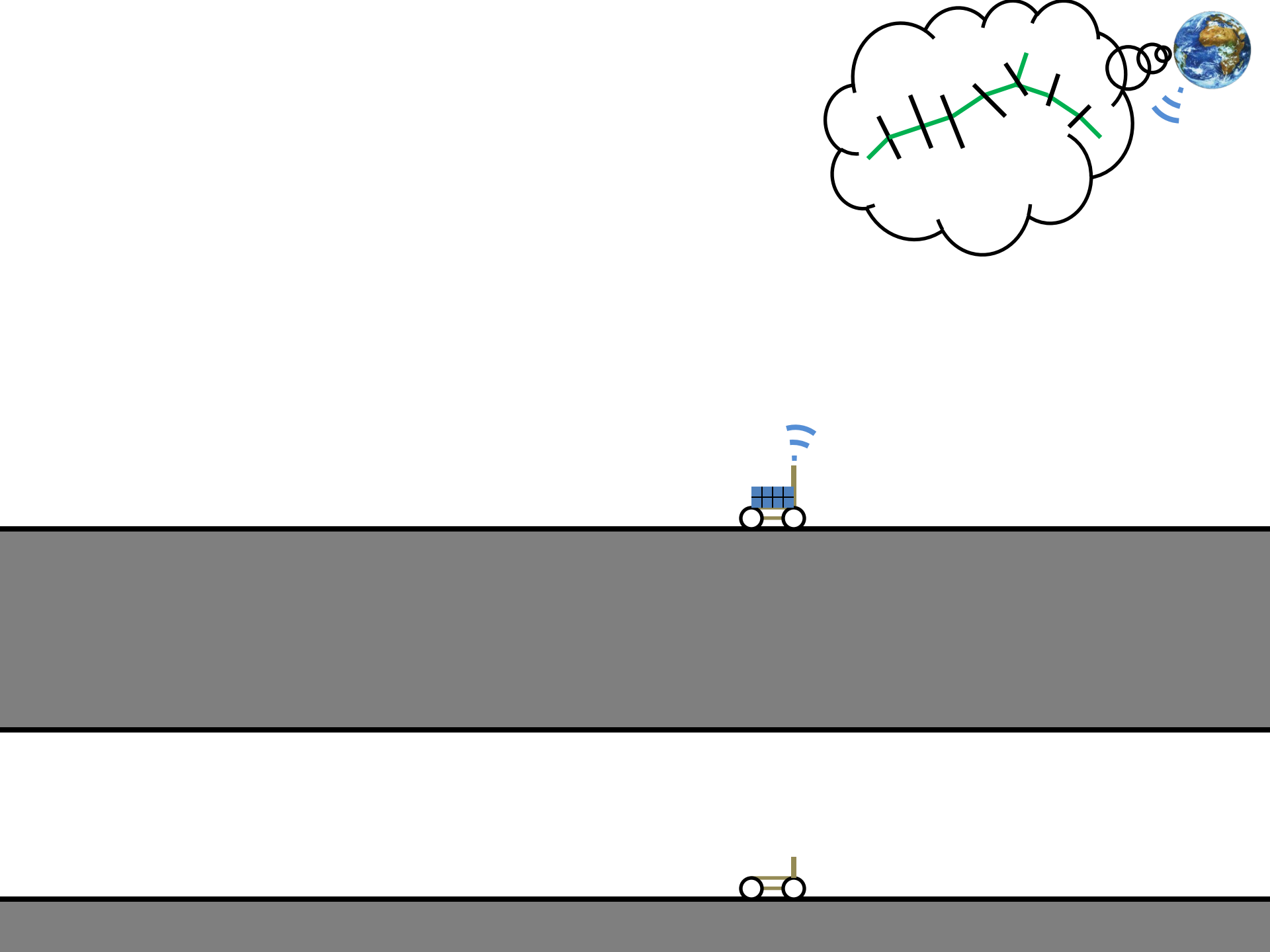


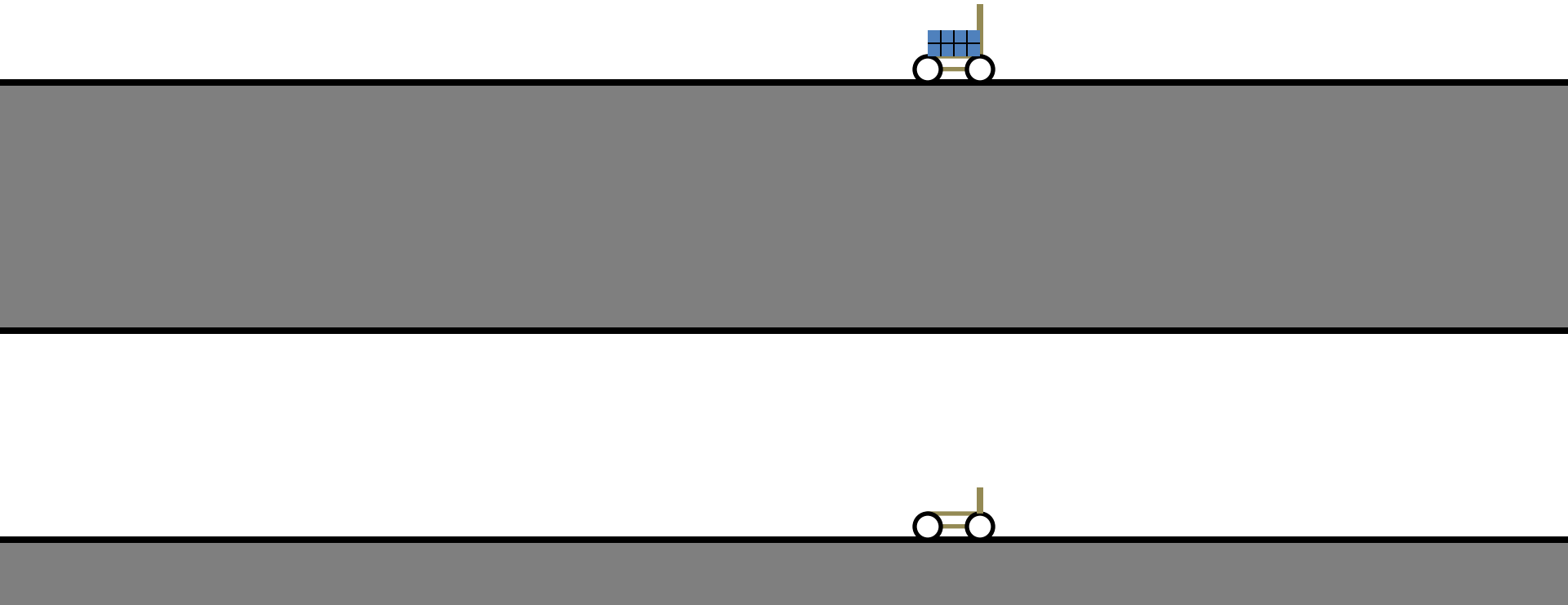


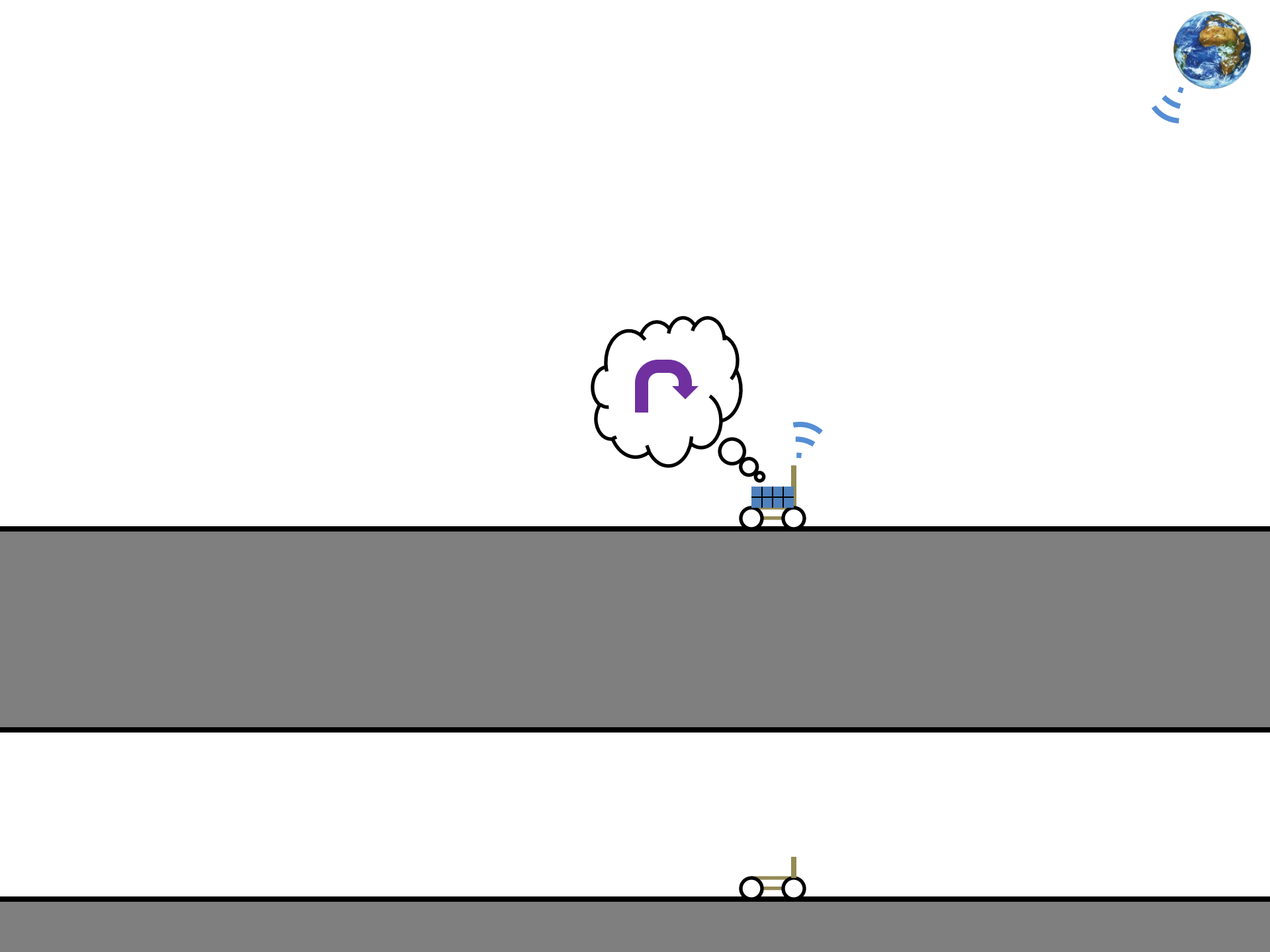


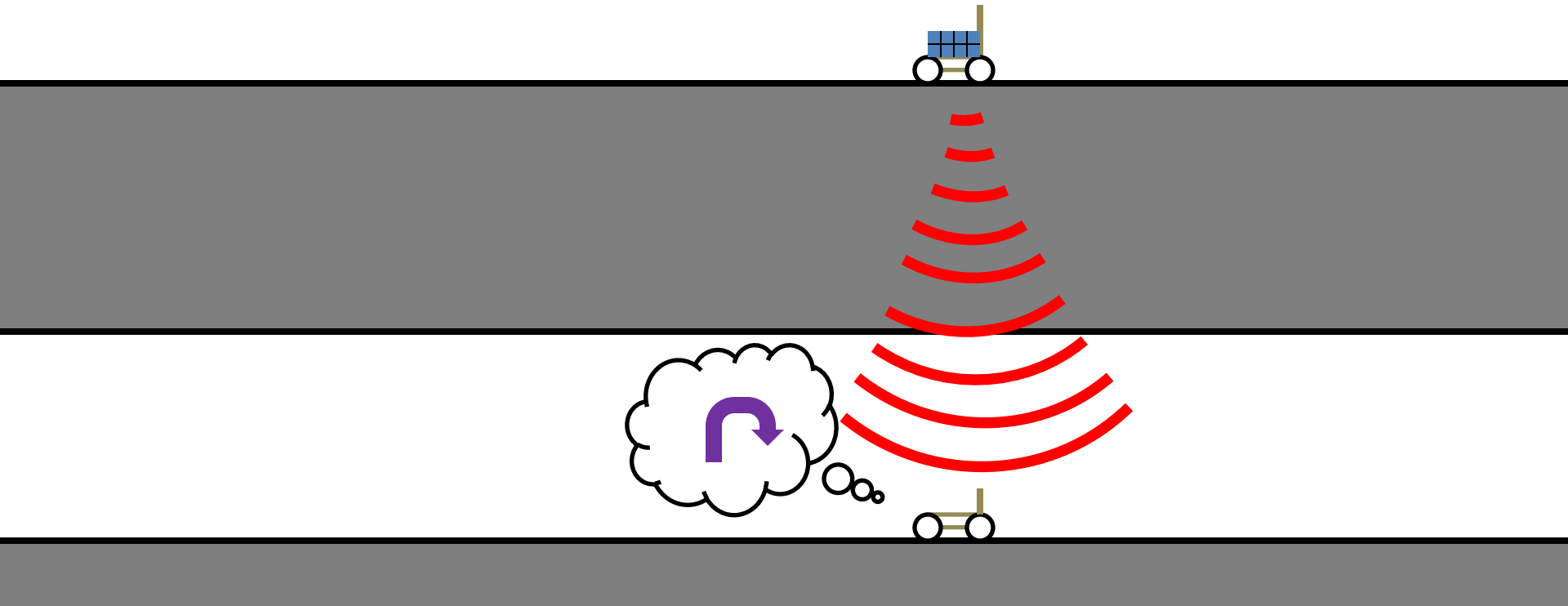


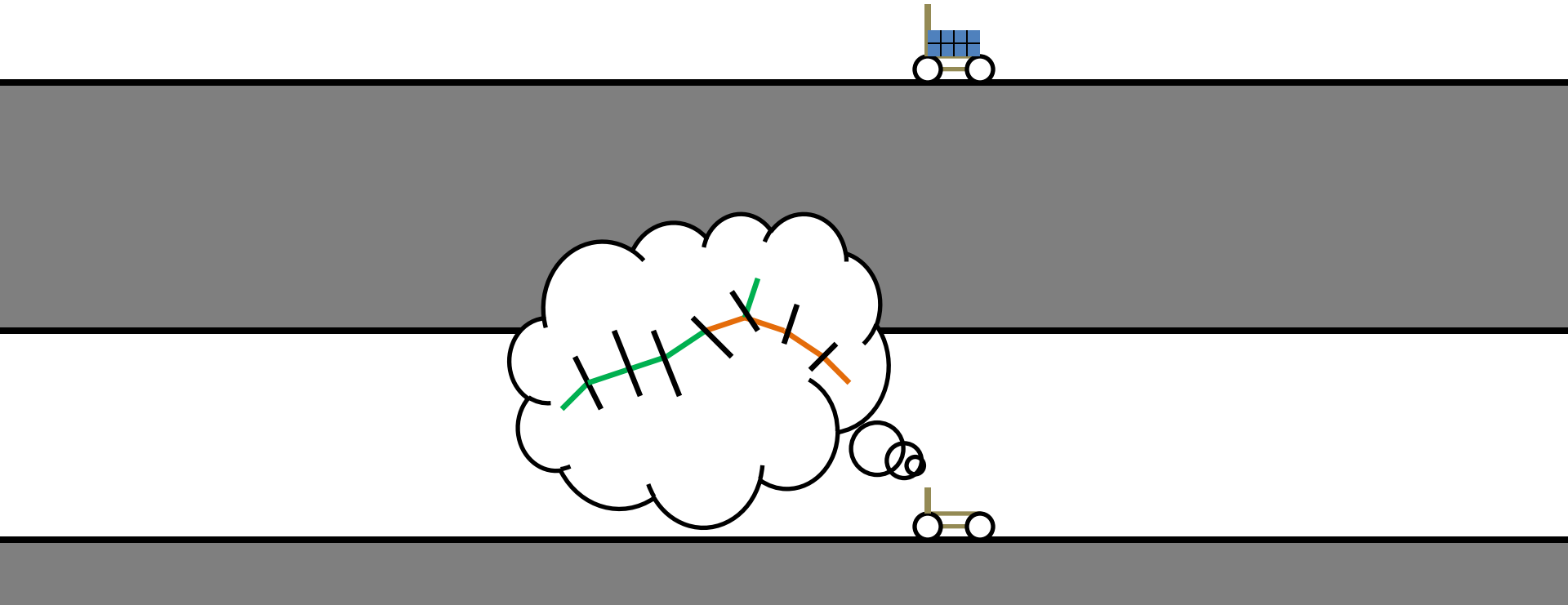


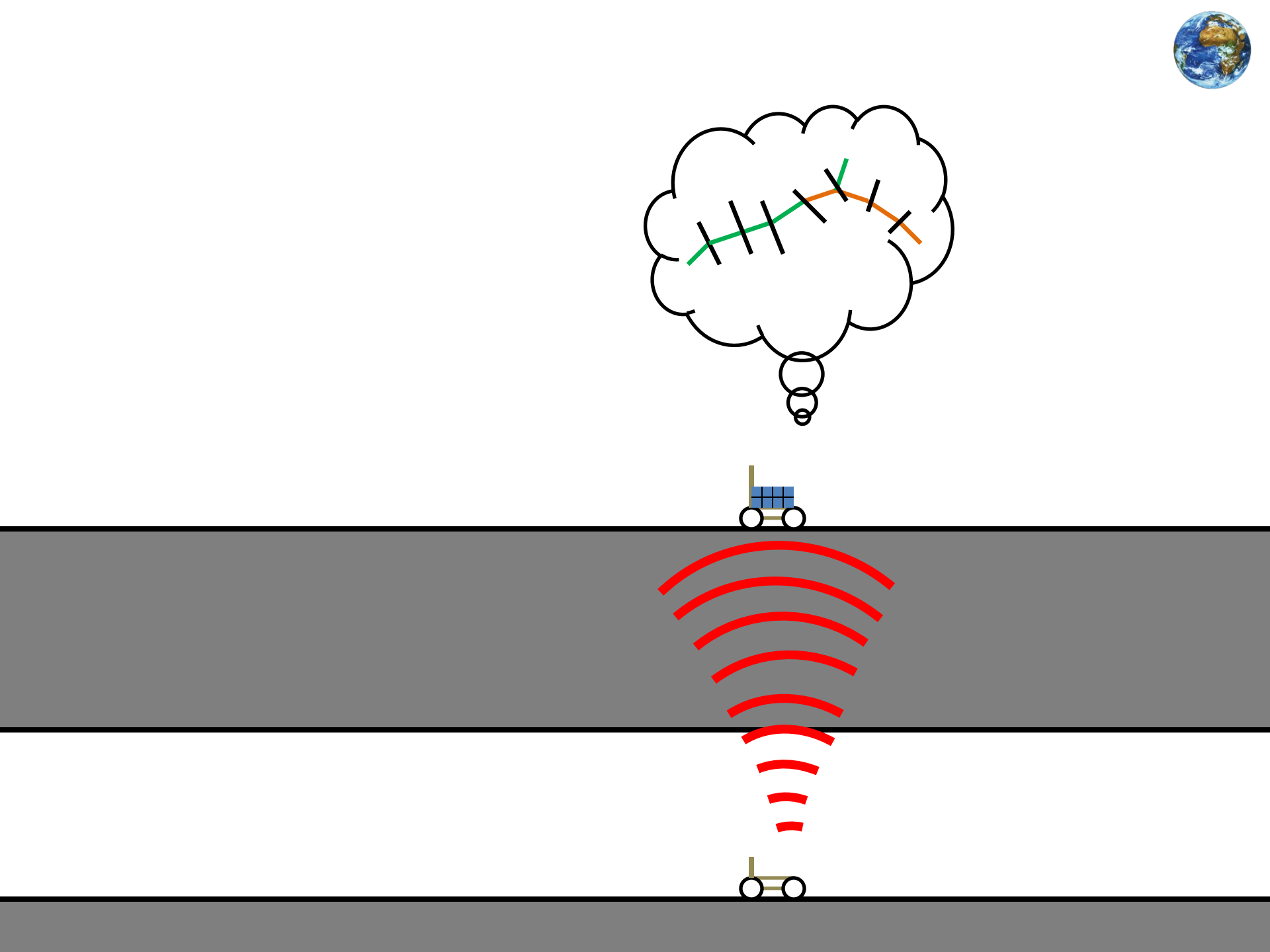


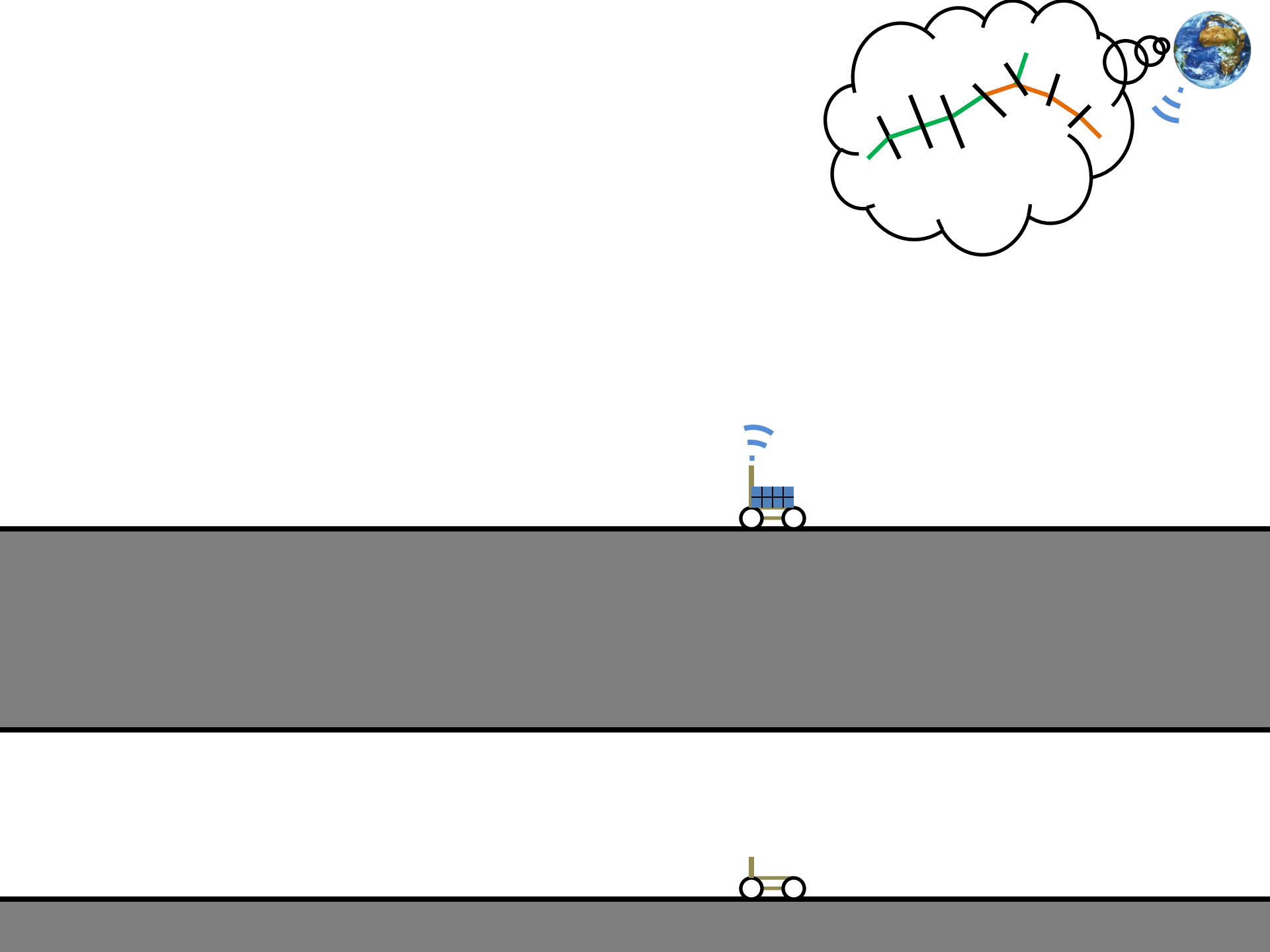


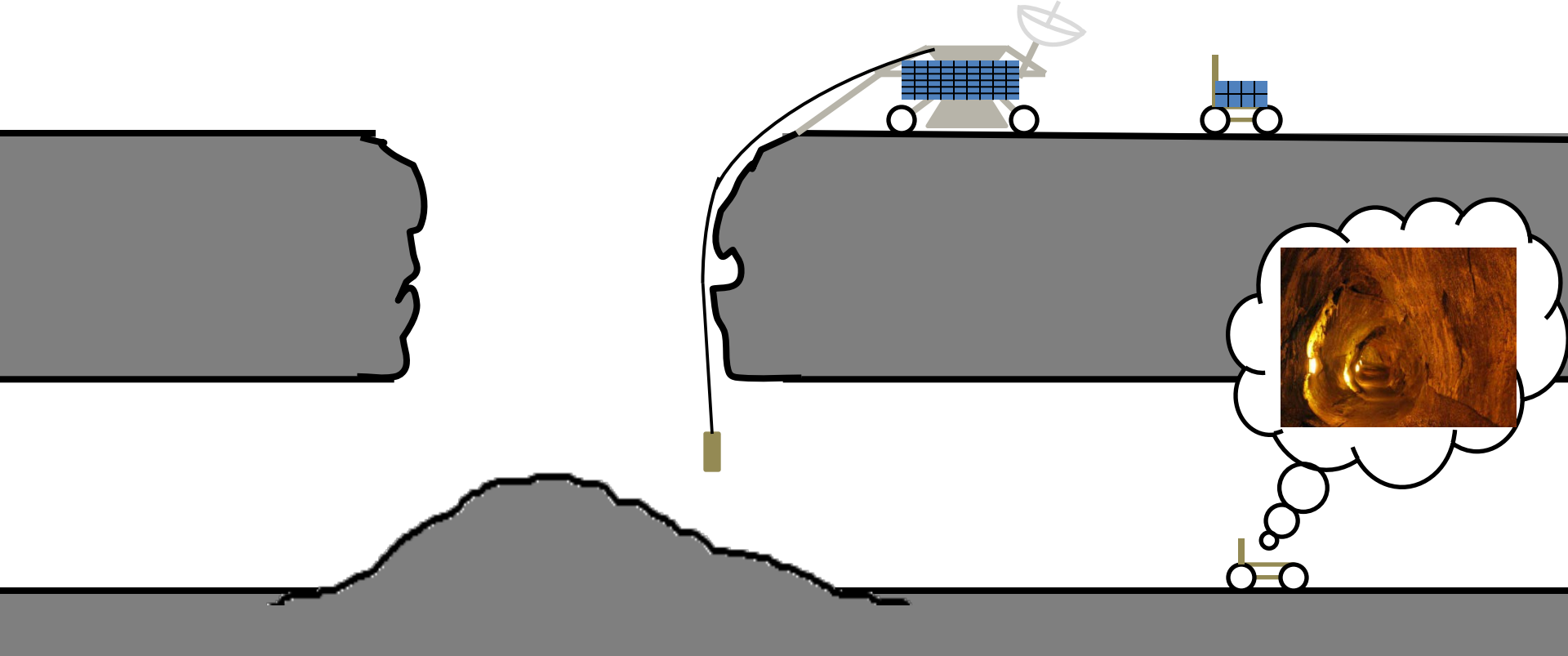


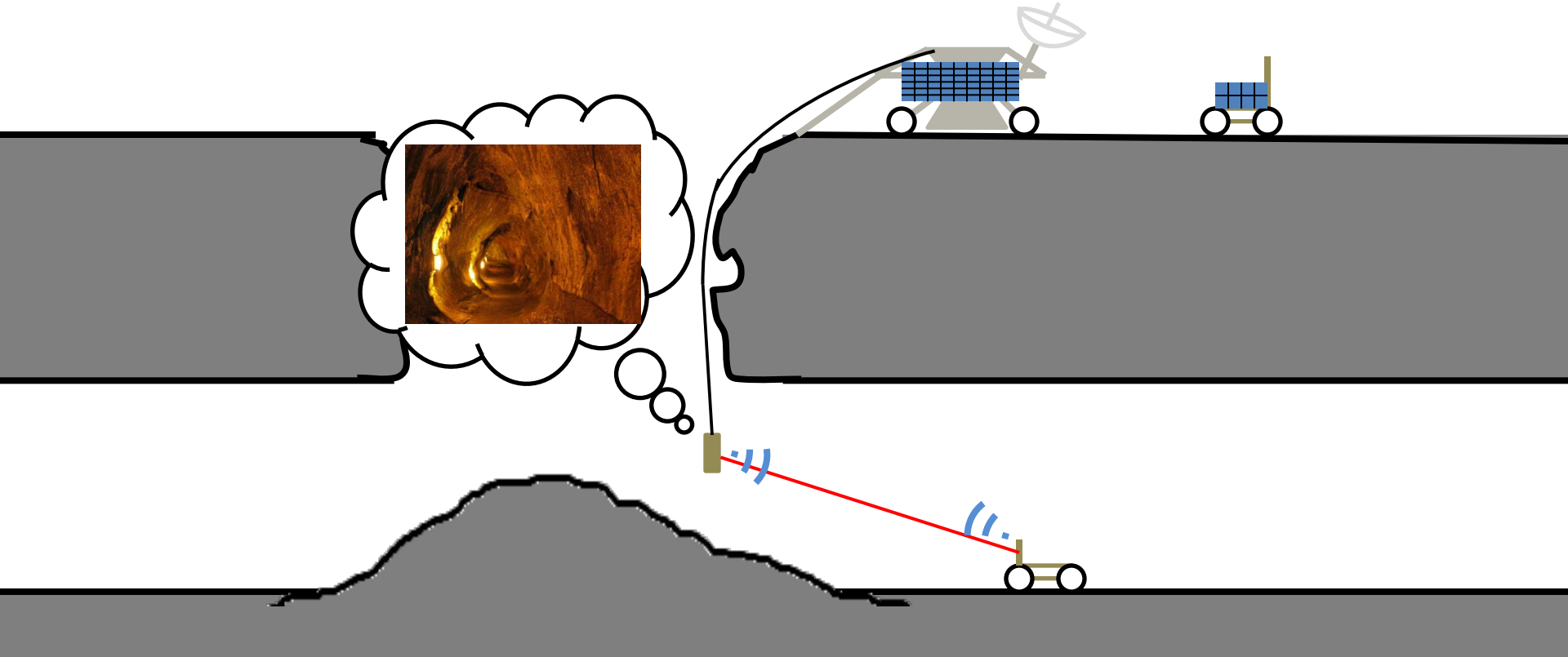


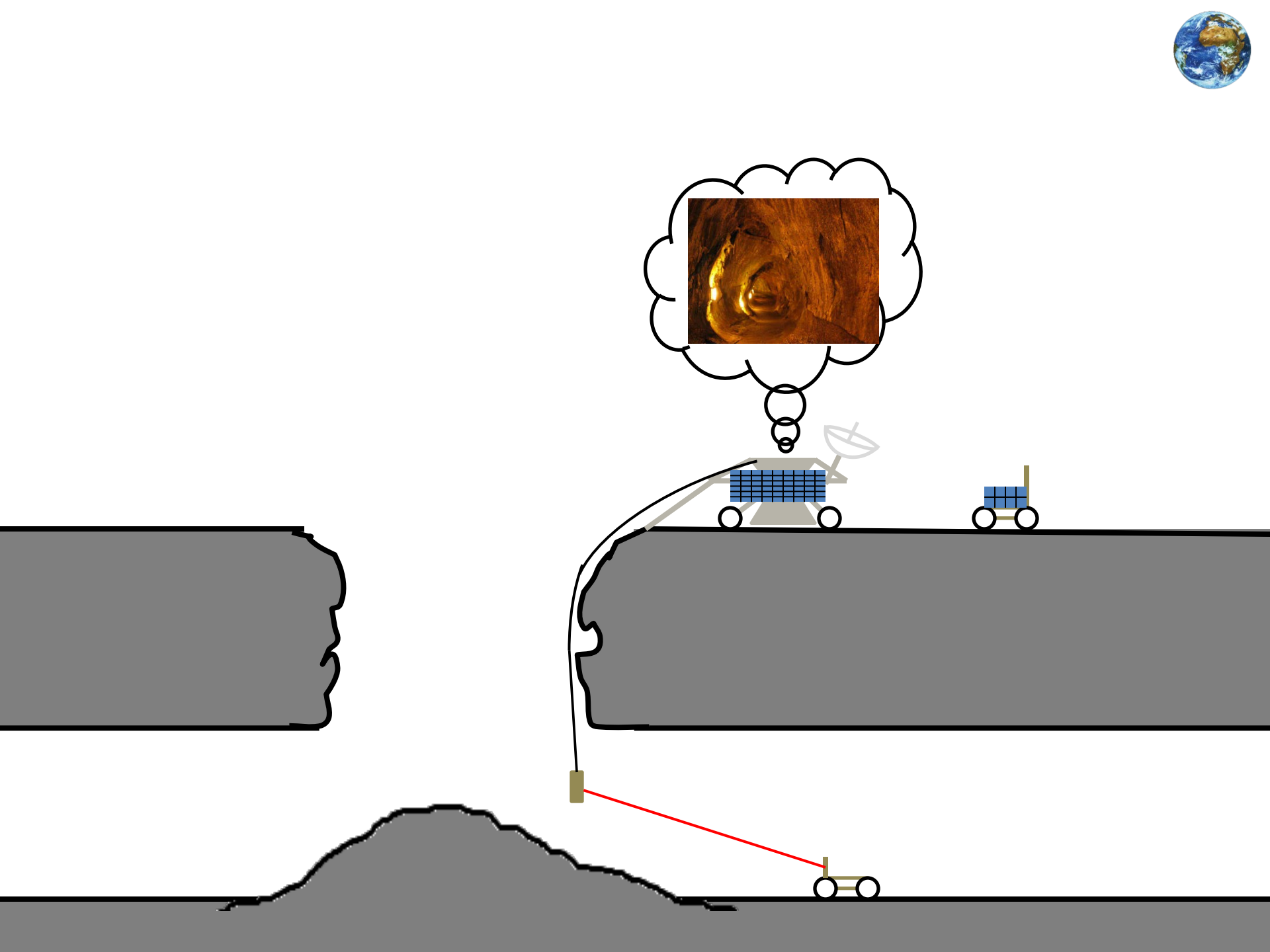


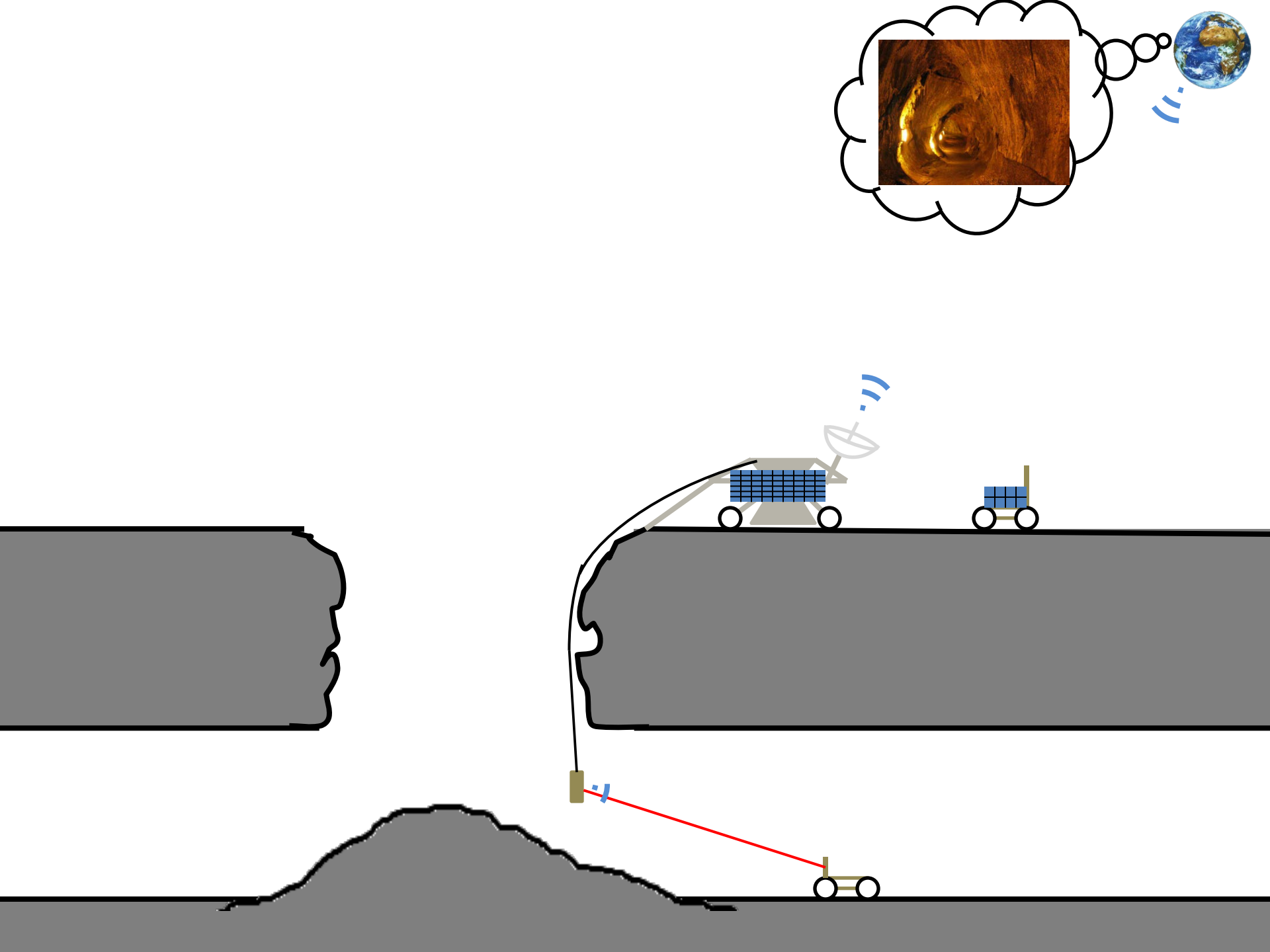












NASA Roadmap Infusion

- **TA04 Top Technical Challenges** include: "Enabling robotic systems to maneuver in a wide range of NASA-relevant environmental, gravitational, surface **and subsurface** conditions.

- Failed with "Skylight" mission proposal

Remaining Goals

- Synthesize Skylight, Apron and Cave
- Complete flyover/rover fusion sim tech
- Perform reduced comm tunnel experiments
- Brainstorm Access and Robot Configuration
- Propose Phase II
  - Relevant robot
  - End-to-end demonstration
- Evangelize skylight and lava tube exploration

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SPACE SCIENCE

BOUND FOR THE MOON

The next rover to roam the moon's surface may come not from NASA and its rocket scientists but from college students and private companies working on a shoestring

By Michael Belfiore

AT A TESTING SITE IN PITTSBURGH, Red Whittaker and his teammates practice remotely controlling Red Rover, a pyramidal robot they hope to get on the moon by 2015.

Photographs by Andrew Hetherington

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Questions?

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